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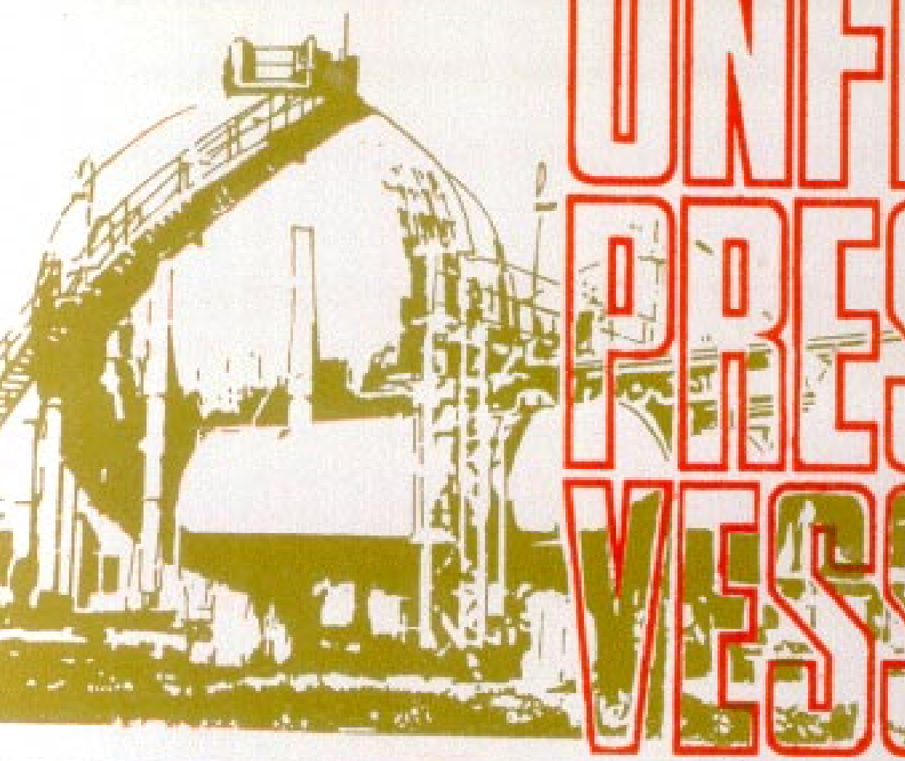

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CODE FOR UNFIRED PRESSURE VESSELS

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CODE FOR UNFIRED PRESSURE VESSELS

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BUREAU OF INDIAN STANDARDS, NEW DELHI

FIRST PUBLISHED MARCH 1971

Fifth Reprint MARCH 1992

Sixth Reprint JANUARY 1994

Seventh Reprint NOVEMBER 1996

Eighth Reprint AUGUST 1998

© BUREAU OF INDIAN STANDARDS

UDC 66.023 : 621.642

Price Rs. **550.00**

PRINTED IN INDIA
AT KAY KAY PRINTERS, DELHI, INDIA AND PUBLISHED BY
BUREAU OF INDIAN STANDARDS, 9 BAHADUR SHAH ZAFAR MARG, NEW DELHI 110 002

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CONTENTS

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 19 March 1969, after the draft finalized by the Unfired Pressure Vessels Sectional Committee had been approved by the Mechanical Engineering Division Council.

0.2 Pressure vessels are widely used in chemical and petroleum industries, for generation of steam and for storage and conveyance of compressed and liquefied gases.

0.3 Boilers and similar steam raising equipment and gas cylinders meant for storage and conveyance of compressed and liquefied gases are covered by statutory regulations in this country. Pressure vessels not coming under the purview of these regulations are not covered comprehensively under any other regulations, though the Indian Factories Act, 1948 and the Rules made thereunder touch upon certain aspects. It was felt, therefore, that a code of practice covering unfired pressure vessels should be prepared.

0.4 Safety of pressure vessels is important and, therefore, it is recommended that pressure vessels are obtained from reliable manufacturers and are manufactured under the survey of a competent engineering inspection authority or organization. The intent of this requirement may be regarded as satisfied when inspection is carried out by a competent personnel of a separate engineering inspection department maintained by the purchaser of the vessel. An inspection department maintained by the manufacturer does not satisfy the requirements except in the case of vessels for the manufacturer's own use and not for resale provided the requirements of statutory regulations are met with.

0.5 Proper inspection of pressure vessels in operation is as important as proper design and manufacture. For the information of the user of the vessel, details of inspection during service are included in Appendix N.

0.6 All pressures in the code, unless otherwise specified, are gauge pressures.

0.7 In the preparation of this code, considerable assistance has been derived from the following publications:

ISO/R 831-1968 Rules for construction of stationary boilers. International Organization for Standardization.

INSTA 20/Sekr. 37-1957 Recommendation regarding welded pressure vessels. Part I: Rules for construction. Dansk Standardiseringsraad (Denmark).

AD Merkblatt H_1 SchweiBen von Druckbehaltern aus Stahl, 1960 (Welding of steel pressure vessels). Vereinigung der Technishen Uberwachungs-Vereine.

Swedish Pressure vessel code 1959. The pressure vessel commission, the Royal Swedish Academy of Engineering Sciences, Stockholm.

Swedish Code for welding of pressure vessels (boiler welding code). The Royal Swedish Academy of Engineering Sciences, Stockholm.

B.S. 1500 :- Fusion welded pressure vessels for use in the chemical, petroleum and allied industries.

Part 1 : 1958 Carbon and low alloy steels.

Part 3 : 1965 Aluminium. British Standards Institution.

B.S. 1515 : Part I : 1965 Fusion welded pressure vessels (advanced design and construction) for use in the chemical, petroleum and allied industries. Part I : Carbon and ferritic alloy steels. British Standards Institution.

B.S. 1515 : Part II : 1968 Austenitic steel fusion welded pressure vessels (advanced design and construction) for use in the chemical, petroleum and allied industries. British Standards Institution.

ASME Boiler and pressure vessel code 1968. The American Society of Mechanical Engineers, New York.

Account has also been taken of the work to date done by ISO/TC 11 Boilers and Pressure Vessels.

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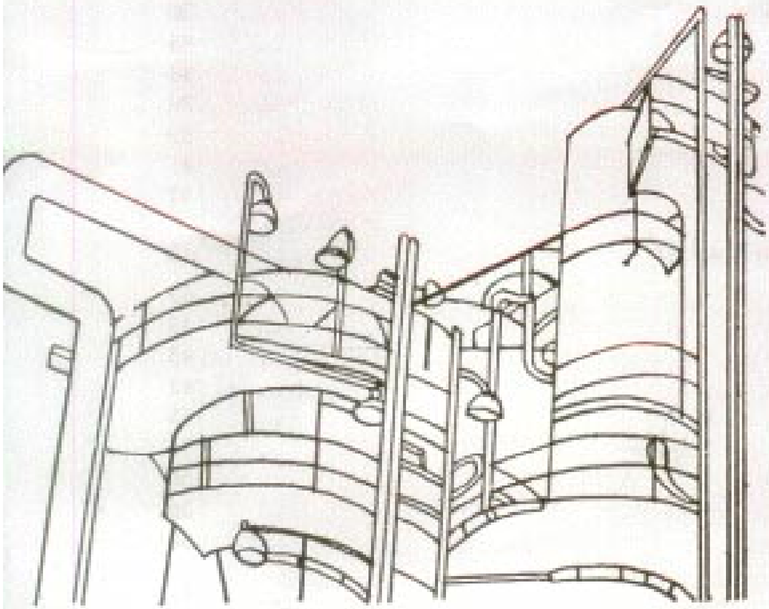
IS : 2825-1969

SECTION I GENERAL, MATERIALS AND DESIGN



CODE FOR UNFIRED PRESSURE VESSELS

1. GENERAL
2. MATERIALS OF CONSTRUCTION AND ALLOWABLE STRESS
3. DESIGN
4. FLANGE CALCULATIONS FOR NON-STANDARD FLANGES
5. PRESSURE RELIEVING DEVICES

SECTION I GENERAL, MATERIALS AND DESIGN

1. GENERAL

1.1 Scope

1.1.1 This code covers minimum construction requirements for the design, fabrication, inspection, testing and certification of fusion welded unfired pressure vessels in ferrous as well as in non-ferrous metals.

1.1.1.1 This code does not include the following:

a) Vessels designed for pressure exceeding 200 kgf/cm²;

b) When the ratio of outside to inside dia (D_o/D_i) of the shell exceeds 1·5;

c) Hot water supply storage tanks heated by steam or any other indirect means when none of the following limitations is exceeded:

   1) a heat input of 50 000 kcal/h,

   2) water temperature of 110°C,

   3) a nominal water capacity of 500 litres;

d) Vessels having an internal operating pressure not exceeding 1 kgf/cm² with no limitations on size;

e) Vessels having an internal diameter not exceeding 150 mm with no limitations on pressure;

f) Steam boilers, steam and feed pipes and their fittings coming under the purview of Indian Boilers Act, 1923, or any revision thereon;

g) Vessels in which internal pressure is due solely to the static head of liquid;

h) Vessels with a nominal water capacity of 500 litres or less for containing water under pressure including those containing air, the compression of which serves only as a cushion;

j) Vessels for nuclear energy application; and

k) Vessels, receivers and tanks covered by other Indian Standards.

1.1.1.2 Nothing in this standard is intended to contravene any provision of the Indian Factories Act, 1948; Indian Boilers Act, 1923; Gas Cylinder Rules, 1940 or any regulations made thereunder.

1.1.2 Fabrication by any fusion welding process is acceptable provided that the requirements of the procedure qualification tests (*see* **7.1**) are met and are acceptable to the inspecting authority.

1.2 Terminology

1.2.0 For the purpose of this code, the following definitions shall apply.

1.2.1 *Pressure Vessels* — All vessels, pipe lines and the like for carrying, storing or receiving steam, gases or liquids at pressures above the atmospheric pressure. The external branches and pipe lines covered by this code shall terminate at the first point of connection by bolting, screwing or welding to the connecting piping.

1.2.2 *Maximum Working Pressure* — The maximum gauge pressure, at the co-incident metal temperature, that is permitted for the vessel in operation. It is determined by the technical requirements of the process.

1.2.3 *Design Pressure* — The pressure (internal or external) including the static head used in the design calculations of a vessel for purpose of determining the minimum thickness of the various component parts of the vessel.

1.2.3.1 It is obtained by adding a minimum of five percent or as may be agreed between the purchaser and the manufacturer, to the maximum working pressure. In the case of vessels subject to inside vacuum and external pressure on the outside, the maximum difference in pressure between the inside and outside of the vessel shall be taken into account.

1.2.4 *Design Temperature* — The temperature used in design shall not be less than the mean metal temperature (through the thickness) expected under the operating conditions for the parts considered except that for parts subject to direct radiations and/or the products of combustion when it shall not be less than the maximum surface temperature expected under operating conditions. In no case shall the temperature at the surface of the metal exceed the maximum temperature listed in the stress tables for materials nor exceed the temperature limitations specified elsewhere in the code.

1.2.4.1 When the occurrence of different metal temperatures during operation can be definitely predicted for different zones of a vessel, the design of the different zones may be based on their predicted temperatures. When sudden cyclic changes in temperature are apt to occur in normal operation with only minor pressure fluctuations, the design shall be governed by the highest probable operating metal temperature (or the lowest, for temperatures below −20°C) and the corresponding pressure.

1.2.4.2 For vessels where direct internal heating is employed or severe exothermic reactions take place, the design temperature shall be at least 25 deg or more than the maximum temperature expected.

1.2.4.3 In case of lined vessels where the wall temperature is expected to be substantially lower than the temperature of contents of the vessel, the design temperature is a matter for agreement between the purchaser and the manufacturer.

1.2.5 *Minimum Thickness* — The thickness obtained by calculation according to formulae in the code. This is only a minimum value and requires to be increased to allow for other factors affecting the use of the vessel as noted below.

1.2.5.1 Vessels or parts of vessels subject to corrosion and erosion (mechanical abrasion) shall have provision made to cover the total amount of the deterioration anticipated over the desired life of the equipment. The actual allowance is a matter for careful consideration and agreement between the purchaser and the manufacturer (*see also* **3.2**).

1.2.5.2 Provision for additional allowances should be made to take care of additional stresses due to:

a) impact loads, including rapidly fluctuating pressure;
b) weight of the vessel and contents under operating and test conditions;
c) superimposed loads, such as other vessels, platforms and ladders, piping, insulation, and corrosion or erosion resistant lining;
d) wind loads and earthquake loads where required;
e) thermal stresses; and
f) reactions of supporting lugs, ring, saddles or other types of supports.

1.2.6 *Weld Joint Efficiency Factor* (*J*) — The ratio of an arbitrary strength of the welded joint to the strength of the plates welded expressed as a decimal.

1.2.7 *Ligament Efficiency* — The ratio of the strength of a ligament to that of the unpierced plate, expressed as a decimal.

1.2.8 *Post-Weld Heat Treatment* — Heat treatment of a vessel or portion of it at a predetermined temperature, to relieve the major portion of the residual stresses.

1.2.9 *Allowable Stress Value* — The maximum stress permissible at the design temperature for any specified material.

1.2.10 *Inspecting Authority* — Duly authorized representative of the purchaser or any other competent authority recognized by the statutory regulations to inspect the vessel and determine its acceptability or otherwise on the basis of this specification.

1.2.11 *Fusion Welding** — Fusion welding shall mean any welding process in which the weld is made between metals in a state of fusion without hammering or pressure. It includes arc welding, gas welding, thermit welding, electron-beam welding and electro-slag welding.

*For other terms relating to welding and cutting, *see* definitions given in IS : 812-1957 '**Glossary of terms relating to welding and cutting of metals**'.

1.3 Classification

1.3.1 The welded pressure vessels covered by this code shall conform to one of the classes shown in Table 1.1. Each class of construction provides for the use in design, of a joint efficiency factor associated with the material, quality control inspection and tests prescribed for that class.

1.3.1.1 *Class 1 vessels*

a) Vessels that are to contain lethal or toxic substances*,
b) Vessels designed for operation below −20°C, and
c) Vessels intended for any other operation not stipulated herein but as agreed to between the purchaser and the manufacturer.

All welded joints of categories A and B of Class 1 vessels shall meet the requirements stipulated in col 3 of Table 1.1. All butt joints shall be fully radiographed. Circumferential butt joints in nozzles, branches and sumps not exceeding 250 mm inside diameter and 28 mm wall thickness need not be radiographed.

The term 'category' as used above specifies the location of the joint in a vessel but not the type of joint. These categories are intended for specifying the special requirements regarding the joint type and degree of inspection for certain locations. The joints included in each category are designated as joints of categories A, B, C and D as shown in Fig. 1.1 and described below:

a) *Category A* — Longitudinal welded joints within the main shell, communicating chambers†, transitions in diameter and nozzles; any welded joint within a formed or flat head.
b) *Category B* — Circumferential welded joints within the main shell, communicating chambers†, nozzles and transitions in diameter including joints between the transition and a cylinder at either the large or small end; circumferential welded joints connecting formed heads to main shells, to transitions in diameter, to nozzles, and to communicating chambers.

*By 'Lethal substances' are meant poisonous gases or liquids of such a nature that a very small amount of the gas or of the vapour of the liquid mixed or unmixed with air is dangerous to life when inhaled. For purposes of the code this class includes substances of this nature which are stored under pressure or generate a pressure if stored in a closed vessel. Some such substances are hydrocyanic acid, carbonyl chloride, cyanogen, mustard gas, and xylyl bromide. For the purposes of this code any liquefied petroleum gas (such as propane, butane, butadiene), natural gas and vapours of any other petroleum products are not classified as lethal substances. *See also* Appendix III of International Labour Office's Model Code of Safety Regulation for Industrial Establishments, for the Guidance of Governments and Industry (1954).

†Communicating chambers are defined as appurtenances to the vessel which intersect the shell or heads of a vessel and form an integral part of the pressure containing enclosures, for example, sumps.

c) *Category C* — Welded joints connecting flanges, van stone laps, tube sheets, and flat heads to main shells, to formed heads, to transitions in diameter, to nozzles or to communicating chambers*, and any welded joint connecting one side plate† to another side plate of a flat sided vessel.

d) *Category D* — Welded joints connecting communicating chambers* or nozzles to main shells, to spheres, to transitions in diameter, to heads and to flat sided vessels, and those joints connecting nozzles to communicating chambers* (for nozzles at the small end of a transition in diameter, *see* Category B).

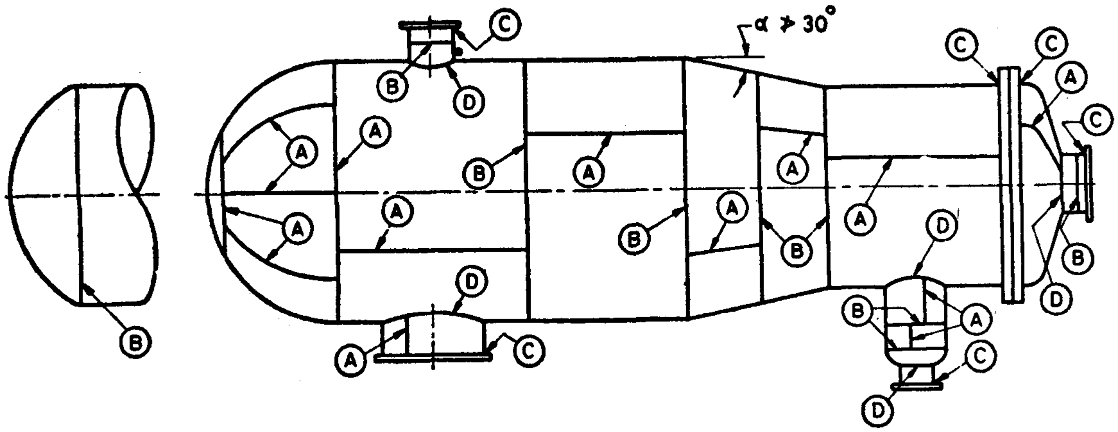


Fig. 1.1 Welded Joint Location Typical of Categories A, B, C and D

TABLE 1.1 CLASSIFICATION OF PRESSURE VESSELS

(*Clause* 1.3.1)

Sl No.	Requirement	Class 1	Class 2	Class 3		
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1.	Weld joint efficiency factor (*J*)	1·00	0·85	0·70	0·60	0·50
2.	Radiography	Fully radiographed (Radiography A) *see* **8.7.1**	Spot radiographed (Radiography B) *see* **8.7.2**	No radiography	No radiography	No radiography
3.	Limitations a) Permissible plate material	Any material allowed under **2.1** except steels to IS : 226-1962* IS : 961-1962† IS : 2062-1962‡ IS : 3039-1965‖	Any material allowed under **2.1** except steels to IS : 226-1962* IS : 961-1962† IS : 2062-1962‡ IS : 3039-1965‖	Carbon and low alloy steels to IS : 226-1962* IS : 961-1962† IS : 2062-1962‡ IS : 2041-1962§ IS : 1570-1961¶ IS : 2002-1965** IS : 3039-1965‖	Carbon and low alloy steels to IS : 226-1962* IS : 961-1962† IS : 2062-1962‡ IS : 2041-1962§ IS : 1570-1961¶ IS : 2002-1965** IS : 3039-1965‖	Carbon and low alloy steels to IS : 226-1962* IS : 961-1962† IS : 2062-1962‡ IS : 2041-1962§ IS : 1570-1961¶ IS : 2002-1965** IS : 3039-1965‖

*Specification for structural steel (standard quality) (*third revision*).

†Specification for structural steel (high tensile) (*revised*).

‡Specification for structural steel (fusion welding quality).

§Specification for steel plates for pressure vessels.

‖Specification for structural steel (shipbuilding quality).

¶Schedules for wrought steels for general engineering purposes.

**Specification for steel plates for boilers.

(*Continued*)

*Communicating chambers are defined as appurtenances to the vessel which intersect the shell or heads of a vessel and form an integral part of the pressure containing enclosures, for example, sumps.

†Side plates of a flat sided vessel are defined as any of the flat plates forming an integral part of the pressure containing enclosures.

TABLE 1.1 CLASSIFICATION OF PRESSURE VESSELS — *Contd*

Sl No.	Requirement	Class 1	Class 2	Class 3		
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	b) Shell or end plate thickness	No limitation on thickness	Maximum thickness 38 mm after adding corrosion allowance	Maximum thickness 16 mm before corrosion allowance is added	Maximum thickness 16 mm before corrosion allowance is added	Maximum thickness 16 mm before corrosion allowance is added
4.	Type of joints	i) Double welded butt joints with full penetration excluding butt joints with metal backing strips which remain in place	i) Double welded butt joints with full penetration excluding butt joints with metal backing strips which remain in place	i) Double welded butt joints with full penetration excluding butt joints with metal backing strips which remain in place	i) Single welded butt joints with backing strip not over 16 mm thickness or over 600 mm outside dia	i) Single full fillet lap joints for circumferential seams only (*see* **6.3.1**)
		ii) Single welded butt joints with backing strip $J=0.9$ (*see* **6.3.6.1**)	ii) Single welded butt joints with backing strip $J=0.80$ (*see* **6.3.6.1**)	ii) Single welded butt joints with backing strip $J=0.65$ (*see* **6.3.6.1**)	ii) Single welded butt joints without backing strip $J=0.55$ (*see* **6.3.6.1**)	—
5.	Quality control					
	a) Material	i) Inspection and tests at steel makers works	i) Inspection and tests at steel makers works	i) Inspection and tests at steel makers works	i) Inspection and tests at steel makers works	i) Inspection and tests at steel makers works
		ii) Identification and marking of plate and other components	ii) Identification and marking of plate and other components	ii) Identification and marking of plate and other components	ii) Identification and marking of plate and other components	ii) Inspection of material and plate edges
		iii) Inspection of material and plate edges	iii) Inspection of material and plate edges	iii) Inspection of material and plate edges	iii) Inspection of material and plate edges	—
	b) During fabrication	i) Visual inspection of surface for objectionable defects	i) Visual inspection of surface for objectionable defects	i) Visual inspection of surface for objectionable defects	i) Visual inspection of surface for objectionable defects	i) Visual inspection of surface for objectionable defects
		ii) Assembly and alignment of vessel sections prior to welding	ii) Assembly and alignment of vessel sections prior to welding	ii) Assembly and alignment of vessel sections prior to welding	ii) Assembly and alignment of vessel sections prior to welding	—
		iii) Identification and stamping of weld test plates	iii) Identification and stamping of weld test plates	iii) Identification and stamping of weld test plates	iii) Inspection during welding in progress, including second side welding grooves after preparation by chipping, gouging, grinding or machining	—
		iv) Inspection during welding in progress, including second side welding grooves after preparation by chipping, gouging, grinding or machining	iv) Inspection during welding in progress, including second side welding grooves after preparation by chipping, gouging, grinding or machining	iv) Inspection during welding in progress, including second side welding grooves after preparation by chipping, gouging, grinding or machining	iv) Calibration and dimensional check on completion	—

(*Continued*)

TABLE 1.1 CLASSIFICATION OF PRESSURE VESSELS — *Contd*

SL No.	REQUIREMENT	CLASS 1	CLASS 2	CLASS 3		
(1)	(2)	(3)	(4)	(5)	(6)	(7)
		v) Inspection of main seams after dressing	v) Inspection of main seams after dressing	v) Calibration and dimensional check on completion	—	—
		vi) Calibration and dimensional check on completion	vi) Calibration and dimensional check on completion	—	—	—
6.	Mechanical test	Mechanical test on longitudinal seams (*see* **8.5.1**)	Mechanical tests on longitudinal seams (*see* **8.5.2**)			
		i) All weld metal tensile test	i) One reduced section tensile test	i) A check bend and tensile test on each plate for material whose specifications do not envisage detailed testing	i) A check bend and tensile test on each plate for material whose specifications do not envisage detailed testing	i) A check bend and tensile test on each plate for material whose specifications do not envisage detailed testing
		ii) One reduced section tensile test	ii) Bend test — outer surface in tension*			
		iii) Three notched bar impact test	iii) Bend test — inner surface in tension*	ii) Bend tests of welded test pieces may be called for at purchaser's option	Nil	Nil
		iv) Bend test — outer surface in tension*				
		v) Bend test — inner surface in tension*				
		vi) Macro and micro examination	iv) One nick break test	—	—	—
7.	Welding procedure and operator qualification	Check on welding procedure and operator qualification (*see* **7.1**)	Check on welding procedure and operator qualification (*see* **7.1**)	Check on welding procedure and operator qualification (*see* **7.1**). Number and type of test pieces as agreed to between purchaser and manufacturer	Check on welding procedure and operator qualification (*see* **7.1**). Number and type of test pieces as agreed to between purchaser and manufacturer	Check on welding procedure and operator qualification (*see* **7.1**). Number and type of test pieces as agreed to between purchaser and manufacturer
8.	Post-weld heat treatment	*See* **6.12**	*See* **6.12**	*See* **6.12**	*See* **6.12**	*See* **6.12**
9.	Pressure test	Hydraulic pressure test (*see* **8.4**)	Hydraulic pressure test (*see* **8.4**)	Hydraulic pressure test (*see* **8.4**)	Hydraulic pressure test (*see* **8.4**)	Hydraulic pressure test (*see* **8.4**)

*Side bend tests are acceptable as alternate to the face and root bend tests [*see* **8.5.1.3** (c) and **8.5.2.2** (b)].

1.3.1.2 *Class* 2 *vessels* — These are vessels that do not fall within the scope of **1.3.1.1** and **1.3.1.3**.

All welded joints of categories A and B (Fig. 1.1) of medium duty vessels shall meet the requirements stipulated in col 4 of Table 1.1. All butt joints of categories A and B shall be spot radiographed (Radiography B **8.7.2**).

1.3.1.3 *Class* 3 *vessels* — These are vessels for relatively light duties, having plate thicknesses not in excess of 16 mm, built for working pressures not exceeding 3·5 kgf/cm² vapour pressure or 17·5 kgf/cm² hydrostatic design pressure, at temperatures not exceeding 250°C and unfired. Class 3 vessels are not recommended for service at temperatures below 0°C.

2. MATERIALS OF CONSTRUCTION AND ALLOWABLE STRESS VALUES

2.1 Materials

2.1.1 The materials used in the manufacture of pressure parts of the vessel constructed according to this code shall be in accordance with this standard and shall, except as provided below, be in accordance with appropriate specifications listed in Appendix A.

2.1.2 Nothing in the foregoing shall preclude the use of otherwise suitable material where so agreed by the purchaser, the manufacturer and the inspecting authority. It is recommended that, in such cases, particular attention be given to the weldability and ductility of the material proposed to be used.

No such material shall have an elongation on a gauge length of $5{\cdot}65\sqrt{S_0}$, less than $\frac{100 - R_m}{2{\cdot}2}$ where S_0 is the original area of cross section and R_m is the actual tensile strength in kgf/mm^2 at room temperature subject to a minimum of 16 percent for carbon and carbon manganese steels, 14 percent for alloy steels other than austenitic steels and 25 percent for austenitic steels, for test pieces obtained, prepared and tested in accordance with appropriate Indian Standards.

2.1.3 Materials used for supporting lugs, skirts, baffles and similar non-pressure parts welded to vessels shall be of weldable quality and suitable in other respects for the intended service.

2.1.4 All material shall be supplied according to IS : 1387-1967* and all threaded fasteners according to IS : 1367-1967†.

2.2 Allowable Stress

2.2.1 The allowable stress values for ferrous and non-ferrous material at the design temperature shall be determined from Table 2.1 by dividing the appropriate properties of the material by the factors given in the table and taking the lowest value.

2.2.1.1 The allowable stress values for carbon and low alloy steels, high alloy steels, copper and copper alloys, aluminium and aluminium alloys, bolting alloys and casting alloys, based on the above criteria, are given in Appendix A. The values for carbon and low alloy steels have been calculated on the basis of the elevated temperature values given in Appendix B and are to be used only for material with no certified or guaranteed elevated temperature properties.

TABLE 2.1 DESIGN STRESS FACTORS FOR VARIOUS MATERIALS

(*Clause* 2.2.1)

Property	Carbon and Carbon Manganese Steels	Low Alloy Steels	Non-ferrous Material Other Than Bolting Material	High Alloy Steels
Certified or specified minimum yield (or 0·2 percent proof) stress* at design temperature	1·5	1·5	1·5	—
Specified minimum tensile stress at room temperature	3·0	3·0	4	2·5
Average stress to produce rupture in 100 000 hours at design temperature	1·5	1·5	1	1·5
Average stress to produce a total creep strain of one percent in 100 000 hours at design temperature	1	1	1	1
Certified 1·0 percent proof stress at design temperature	—	—	—	1·50

NOTE — In the case of castings, the above factors shall be divided by a quality factor of 0·75. However, a quality factor of 0·9 shall be used when the following requirements have been met with:

a) Each casting has been radiographically examined at all critical locations and found free from harmful defects, or the castings have been fully machined to such an extent that all critical sections are exposed for the full thickness as in the case of tube plates with holes spaced not further apart than the thickness of the casting.

b) All castings have been examined at all critical locations using magnetic particle, or penetrant fluid procedure (*see* IS : 3658-1966† and IS : 3703-1966‡) or by grinding or machining and etching.

c) Castings found to be defective have been rejected or repaired to the satisfaction of the inspecting authority. If repairs by welding are carried out, the castings should be subsequently stress-relieved or heat-treated as agreed between the steel-maker and the inspecting authority. Repaired areas of castings should be re-examined in accordance with (a) above and should be shown to be free from harmful defects. In all other cases a factor of 0·75 shall be used instead of 0·90.

*The minimum specified yield stress (at room temperature) may be taken to apply for all temperatures up to 50°C.

†Code of practice for liquid penetrant flaw detection.

‡Code of practice for magnetic particle flaw detection.

*General requirements for the supply of metallurgical materials (*first revision*).

†Technical supply conditions for threaded fasteners (*first revision*).

2.2.2 Where safe stress values for material in compression are required, for example, in the case of the design of vessels subject to loadings (*see* **1.2.5.2** and **3.3.2.4**) that produce longitudinal compressive stresses, it shall be calculated as given in Appendix C.

2.2.3 *Shear Stresses* — The maximum permissible shear stress (where present alone) shall not exceed 50 percent of the allowable stress value.

2.2.4 *Bearing Stresses* — The maximum permissible bearing stress shall not exceed 50 percent of the allowable stress value.

2.3 Materials for Low Temperature Service — Special consideration shall be given to the choice of materials for vessels designed for operation below 0°C. Aluminium and its alloys not being subject to brittle fracture are particularly suitable for operation at temperatures below 0°C. Austenitic stainless steels (wrought) are quite suitable fot use up to −200°C. For use below this temperature or where cast materials are used special consideration shall be given to the choice of material and design. A recommended practice for carbon and low alloy steel vessels required to operate at low temperatures is given in Appendix D.

2.4 Materials for Welding — The electrodes, filler rods and flux shall satisfy the requirements of appropriate Indian Standards and shall correspond to those used in the procedure qualification tests and welder's performance tests. The following Indian Standards are available or under preparation:

IS : 814-1970	Specification for covered electrodes for metal arc welding of structural steel (*third revision*)
IS : 1278-1967	Specification for filler rods and wires for gas welding (*first revision*)
IS : 1395-1964	Specification for molybdenum and chromium molybdenum low alloy steel electrodes for metal arc welding (*revised*)
IS : 2680-1964	Specification for filler rods and wires for inert gas tungsten arc welding
IS : 3613-1966	Specification for acceptance tests for wire flux combinations for submerged arc welding
IS : 4972-1969	Specification for resistance spot welding electrodes
IS : 5206-1969	Specification for corrosion resisting chromium and chromium nickel steel covered electrodes for metal arc welding
IS :	Specification for filler wires for metal inert gas welding (*under preparation*)
IS :	Specification for filler rods and wires for inert gas welding (*under preparation*)

3. DESIGN

3.1 General — Vessels covered by this code shall be designed for the most severe combinations of operating conditions which may be experienced in the normal operations.

Special consideration shall be given to vessels designed to operate at temperatures below 0°C. A tentative recommended practice for vessels required to operate at low temperatures is given in Appendix D.

Where vessels are subject to alternate heating and cooling, provision shall be made in the design to permit expansion or contraction to avoid excessive thermal stresses (*see* Appendix E).

This code does not contain rules to cover all details of design and construction. Where complete details are not given, it is the intention that the manufacturer, subject to the approval of the purchaser and/or the inspecting authority, shall follow such details of design and construction which will be as safe as those provided by this code.

3.1.1 *Design Thickness* — In the clauses that follow, methods are given for calculating the thicknesses required for the various parts of a pressure vessel.

3.1.2 *Weld Joint Efficiency Factors* (*J*) — The weld joint efficiency factors to be used in the design calculations shall be those specified in Table 1.1.

3.1.3 *Loadings*

3.1.3.1 In the design of a vessel the following loadings shall be included where relevant:

a) Design pressure including static head;
b) The weight of vessel and normal contents, or weight of the vessel and maximum content of water specified for the pressure test; and
c) Wind loading in combination with other loadings.

3.1.3.2 Special consideration may be required to be given to the effect of the following:

a) Local stresses due to supporting lugs, ring girders, saddles, internal structures or connecting piping;
b) Shock loads due to water hammer or surging of vessel contents;
c) Bending moments caused by eccentricity of the centre of working pressure relative to the neutral axis of the vessel;

d) Forces due to temperature differences, including the effects of differential expansion;

e) Forces caused by the method of supporting the vessel during transit or erection; and

f) Fluctuating pressure and temperature (*see* Appendix E).

Formal analysis of the effect of the above influences is only required in cases where it is not possible to demonstrate the adequacy of the proposed design, for example, by comparison with the behaviour of comparable vessels.

3.2 Corrosion, Erosion and Protection

3.2.1 *General*

3.2.1.1 Whenever the word corrosion is used in this code it shall be taken to mean corrosion, oxidation, scaling, abrasion, erosion and all other forms of wastage. Stress corrosion cracking may occur under certain conditions of temperature and environment and cannot be catered for by increasing thicknesses. Under conditions where stress corrosion may occur, consideration shall be given to the materials used and the residual stress in fabricated vessels.

It is impossible to lay down definite precautionary rules to safeguard against the effects of corrosion owing to the complex nature of corrosion itself, which may exist in many forms, for example:

a) Chemical attack, where the metal is dissolved by the reagents, it may be general over the whole surface, or localized (causing pitting), or a combination of the two;

b) Rusting, caused by the combined action of moisture and air;

c) Erosion, where a reagent, otherwise innocuous, flows over the surface at a velocity greater than some critical value; and

d) High temperature oxidation (scaling).

Designers should give careful consideration to the effect which corrosion may have upon the useful life of the vessel. When in doubt, corrosion tests should be undertaken; these should be carried out on the actual metal (including welds) or combination of metals under exposure to the actual chemicals used in service. It is very dangerous to assume that the major constituent of a mixture of chemicals is the active agent as, in many cases, small traces of impurities exert an accelerating or inhibiting effect out of all proportion to the amount of impurity present. Fluid temperatures and velocities should be equivalent to those met with in operation. Corrosion tests should be continued for a sufficiently long period to determine the trend of any change in the rate of corrosion with respect to time; the result may be considered as given below. Corrosion may occur on both sides of the wall of the vessel, particularly with vessels heated by hot gases of combustion:

a) *Corrosion rate predictable* — Vessels in which corrosion rates may be definitely established by reason of accurate knowledge of the chemical characteristics of whatever substances they are to contain.

b) *Corrosion rate unpredictable* — Vessels in which corrosion rates are either variable throughout the vessel or indeterminate in magnitude.

c) *Corrosion rate negligible* — Vessels in which corrosion rates are known to be negligible.

3.2.2 *Additional Thickness to Allow for Corrosion*— The allowances adopted shall be adequate to cover the total amount of corrosion expected on either or both surfaces of the vessel.

In cases where corrosion may occur, additional metal thickness over and above that required for the design conditions should be provided, at least equal to the expected corrosion loss during the desired life of the vessel. It is recommended that in all such cases a minimum corrosion allowance of 1·5 mm should be provided unless a protective lining is employed.

Where the corrosion effects are negligible, no excess thickness need be provided.

3.2.3 *Linings* — Vessels may be fully or partially lined with corrosion-resistant material. Such linings may be loose, intermittently attached to the vessel base material or integrally bonded to the vessel base material (for example, as clad steel). This code does not cover vitreous enamel linings.

Provided linings are designed so as to exclude contact between the corrosive agent and the vessel base material, no corrosion allowance need be provided against internal wastage of the base material.

Corrosion-resistant linings shall not be included in the computation of the required wall thickness, except in the case of clad steels as may be agreed to between the purchaser and the manufacturer.

The design of linings should take into account the effects of differential thermal expansion.

3.2.4 *Wear Plates* — Where severe conditions of erosion and abrasion arise, local protective or 'wear plates' of an easily renewable type should be fitted directly in the path of the impinging material.

3.3 Cylindrical and Spherical Shells

3.3.1 *General*

3.3.1.1 The thickness shall be not less than that calculated by the following formulae and shall be increased, if necessary, to meet the requirements of **3.1** and **3.2**.

3.3.2 *Shells Subject to Internal Pressure*

3.3.2.1 *Notation* — The following notations are used in the design of spherical and cylindrical vessels subject to internal pressure:

t = minimum thickness of shell plates exclusive of corrosion allowance in mm,

p = design pressure in kgf/cm²,
D_i = inside diameter of the shell in mm,
D_o = outside diameter of the shell in mm,
f = allowable stress value in kgf/mm² (*see* Appendix A),
J = joint factor (*see* Table 1.1), and
E = modulus of elasticity of the material at the operating temperature in kgf/mm² (*see* Tables 3.1, 3.2, 3.3 and 3.4).

3.3.2.2 *Cylindrical shells* — The following formulae shall apply in the case of cylindrical shells:

$$t = \frac{pD_i}{200fJ-p} = \frac{pD_o}{200fJ+p} \qquad \ldots(3.1)$$

or

$$p = \frac{200fJt}{D_i+t} = \frac{200fJt}{D_o-t} \qquad \ldots(3.2)$$

3.3.2.3 *Spherical shells* — The following formulae shall apply in the case of spherical shells:

$$t = \frac{pD_i}{400fJ-p} = \frac{pD_o}{400fJ+p} \qquad \ldots(3.3)$$

or

$$p = \frac{400fJt}{D_i+t} = \frac{400fJt}{D_o-t} \qquad \ldots(3.4)$$

3.3.2.4 *Cylindrical vessels under combined loadings* — Under no circumstances shall the shell thickness (before adding corrosion allowance) be less than that given in equation (3.1).

Where the shell is subjected to loadings additional to those due to internal pressure, the basis of design shall be that the stress equivalent to the membrane stresses shall nowhere exceed the allowable stress.

The equations given below apply to the case where the cylinder is subjected to loads producing a direct longitudinal stress (for example, from its own weight in the case of a vertical vessel), a longitudinal bending moment (for example, from wind or piping loads or, in the case of a horizontal vessel, the weight of the vessel and contents) and a torque about the longitudinal axis (for example, from offset piping and wind loads).

The following notation is adopted:

f = allowable stress in kgf/mm²;
f_a = allowable stress at ambient temperature in kgf/mm²;
p = internal pressure (design or test as appropriate) in kgf/cm²;
t = shell thickness (before adding corrosion allowance) in mm;
t_a = actual shell thickness at time of test (including corrosion allowance) in mm;
$\left.\begin{matrix} D_i \\ D_o \end{matrix}\right\}$ = internal, external diameters of shell in mm;
$\left.\begin{matrix} E \\ E_a \end{matrix}\right\}$ = young modulus at design temperature and at ambient temperature respectively in kgf/mm² (*see* Tables 3.1, 3.2, 3.3 and 3.4);
M = longitudinal bending moment in kgf.mm;
T = torque about vessel axis in kgf.mm;
W = weight (vertical vessel only) in kg:

a) for points above plane of support — weight of vessel, fittings, attachments and fluid supported above the point considered, the sum to be given a negative sign in equation (3.5);

b) for points below plane of support — weight of vessel, fittings and attachments below the point considered, plus weight of fluid contents, the sum to be given a positive sign in equation (3.5);

σ_e = equivalent stress (shear strain energy basis) in kgf/mm²;
σ_z = longitudinal stress in kgf/mm²;
σ_θ = hoop stress in kgf/mm²; and
τ = shearing stress in kgf/mm².

Then

$$\sigma_z = \frac{\frac{\pi}{400}pD_i^2 + W \pm 4\frac{M}{D_i}}{\pi t\,(D_i+t)} \qquad \ldots(3.5)$$

$$\sigma_\theta = \frac{p(D_i+t)}{200t} \qquad \ldots(3.6)$$

$$\tau = \frac{2T}{\pi t D_i\,(D_i+t)} \qquad \ldots(3.7)$$

The stress equivalent to the membrane stress on the shear strain energy criterion is given by the Huber-Hencky equation:

$$\sigma_e = \left[\sigma^2_\theta - \sigma_\theta\,\sigma_z + \sigma_z^2 + 3\tau^2 \right]^{\frac{1}{2}} \qquad \ldots(3.8)$$

The requirements are that at design conditions:

$$\sigma_e \leqslant f \qquad \ldots(3.9a)$$

$$\sigma_z \text{ (tensile) } \leqslant f \qquad \ldots(3.9b)$$

$$\sigma_z \text{ (compressive) } \leqslant 0{\cdot}125\, E \left(\frac{t}{D_o} \right) \qquad \ldots(3.9c)$$

and at test conditions (*see* **8.4**)

$$\sigma_e \leqslant 1{\cdot}3 f_a \qquad \ldots(3.9d)$$

$$\sigma_z \text{ (tensile) } \leqslant 1{\cdot}3 f_a \qquad \ldots(3.9e)$$

$$\sigma_z \text{ (compressive) } \leqslant 0{\cdot}125\, E_a \left(\frac{t_a}{D_o} \right) \qquad \ldots(3.9f)$$

In all cases each of the signs before the term $4M/D_i$ in equation (3.5) should be considered.

Values of σ_z, σ_e and τ should be determined for each combination of loading during operation and test.

The equations cannot be reduced to a convenient explicit expression for the calculation of t and solution by trial and error is necessary.

TABLE 3.1 VALUES OF *E* FOR FERROUS MATERIALS IN 10^3 kgf/mm²

(*Clauses* 3.3.2.1 *and* 3.3.2.4)

Material		Design Temperature °C						
		0	20	100	200	300	400	500
Carbon	C⩽0·30 %	19·6	19·6	19·5	19·0	18·2	17·0	—
Steels	C>0·30 %	21·1	21·0	20·7	19·9	19·0	17·3	—
Carbon-molybdenum steels and chrome-molybdenum steels (up to 3 % Cr)		21·1	21·0	20·7	20·1	19·4	18·1	17·2
Intermediate chrome molybdenum steels and austenitic stainless steels		19·3	19·3	19·0	18·6	18·0	17·3	16

NOTE — Intermediate values may be obtained by interpolation.

TABLE 3.2 VALUES OF *E* FOR ALUMINIUM AND ITS ALLOYS IN 10^3 kgf/mm²

(*Clauses* 3.3.2.1 *and* 3.3.2.4)

Material Grade	Design Temperature °C								
	−200	−100	0	50	75	100	125	150	200
1B, N3, N4	7·8	7·4	7·1	7·0	7·0	6·9	6·8	6·7	6·4
H9	7·4	7·1	6·8	6·6	6·6	6·5	6·5	6·3	6·0
H15	8·3	7·9	7·5	7·4	7·4	7·3	7·2	7·1	6·8
A6	8·9	8·5	8·2	8·1	8·0	7·9	7·8	7·7	7·4

NOTE 1 — Intermediate values may be obtained by interpolation.

NOTE 2 — Since aluminium and its alloys do not have a well-defined yield point, the above values of *E* are to be used with caution.

TABLE 3.3 VALUES OF *E* FOR NICKEL AND NICKEL ALLOYS IN 10^3 kgf/mm²

(*Clauses* 3.3.2.1 *and* 3.3.2.4)

Material	Design Temperature °C						
	20	300	400	500	600	700	750
Nickel	21·1	20·4	18·8	16·5	14·0	11·7	10·9
70 % Nickel and 30 % copper alloy	18·8	18·0	17·6	16·9	16·2	15·5	15·0
75 % Nickel, 15 % chromium and 10 % ferrous alloy	21·8	20·7	20·0	17·6	16·0	13·0	11·9

TABLE 3.4 VALUES OF *E* FOR COPPER AND ITS ALLOYS IN 10^3 kgf/mm²

(*Clauses* 3.3.2.1 *and* 3.3.2.4)

Material	Composition	Design Temperature °C								
		20	50	100	150	200	250	300	350	400
Copper	99·98 % Cu	11·2	11·1	11·0	10·8	10·6	10·4	10·1	9·7	—
Commercial brass	66 % Cu, 34 % Zn	9·8	9·7	9·6	9·5	9·1	8·9	8·6	8·5	—
Leaded tin bronze	88 % Cu, 6 % Sn, 1·5 % Pb, 4·5 % Zn	9·1	9·0	8·9	8·7	8·4	8·2	8·0	7·7	—
Phosphor bronze	85·5 % Cu, 12·5 % Sn, 10 % Zn	10·5	10·3	10·2	9·8	9·5	9·1	8·5	6·7	—
Muntz	59 % Cu, 39 % Zn	10·7	10·2	9·8	9·1	8·3	7·7	—	—	—
Cupro nickels	80 % Cu, 20 % Ni or 70 % Cu & 30 % Ni	13·3	13·1	12·9	12·6	12·4	12·1	11·8	11·5	14·2

NOTE — Intermediate values may be obtained by interpolation.

3.3.3 *Shells Subjected to External Pressure* - The thickness of thin-walled shells subjected to external pressure may be calculated either by the formulae given below or by the method given in Appendix F.

3.3.3.1 *Notation* — The following notation has been used in the formulae in this section:

t = minimum thickness of the shell material in mm,

D_o = outer diameter of the shell in mm, and

L = effective length in mm.

In the case of cylindrical shells, it is the maximum of the following values and is measured parallel to the axis of the shell:

a) The distance between head bend lines plus one-third the depth of each head, when no stiffening rings are present;
b) the maximum centre distance between two adjacent stiffening rings; and
c) the distance from the centre of the nearest stiffening to the head bend line plus one-third the depth of the head.

In the case of spherical shells, the effective length is equal to the inside radius of the spherical shell:

p = design pressure in kgf/cm²;

σ = 0·2 percent proof stress in kgf/mm²; and

K = the ratio of the elastic modulus E of the material at the design metal temperature to the room temperature elastic modulus (*see* Tables 3.1, 3.2, 3.3 and 3.4 for values of E at different temperatures).

3.3.3.2 *Thickness of cylindrical shells under external pressure* — The thickness of the cylindrical shells under external pressure is given by equations 3.10, 3.11, or 3.12 as is applicable:

a) for $\frac{L}{D_o} < \frac{0{\cdot}58\left(\frac{10p}{\sigma}\right)^{\frac{5}{2}}}{pK}$ or $< \frac{38\left(\frac{100t}{D_o}\right)^{\frac{3}{2}}}{K\sigma}$

$$t = \frac{D_o}{100}\left[\frac{1{\cdot}15p}{\sigma} + 0{\cdot}053\left(\frac{K\sigma L}{D_o}\right)^{\frac{2}{3}}\right] \quad \ldots(3.10)$$

$$\text{or } p = \frac{\sigma}{1{\cdot}15}\left[\frac{100t}{D_o} - 0{\cdot}053\left(\frac{K\sigma L}{D_o}\right)^{\frac{2}{3}}\right] \quad \ldots(3.10a)$$

b) for $\frac{L}{D_o} > \frac{14{\cdot}4}{(pK)^{\frac{1}{6}}}$ or $> \frac{14{\cdot}6}{\sqrt{\frac{100t}{D_o}}}$; or

$$\frac{0{\cdot}58\left(\frac{10p}{\sigma}\right)^{\frac{5}{2}}}{pK} > \frac{14{\cdot}4}{(pK)^{\frac{1}{6}}};$$

$$\text{or } 38\,\frac{\left(\frac{100t}{D_o}\right)^{\frac{3}{2}}}{K\sigma} > \frac{14{\cdot}6}{\sqrt{\frac{100t}{D_o}}}$$

$$t = 1{\cdot}03 \times \frac{D_o}{100} \times (pK)^{\frac{1}{3}} \text{ but not less than } \frac{3{\cdot}5pD_o}{200\sigma} \quad \ldots (3.11)$$

$$\text{or } p = \frac{0{\cdot}91}{K} \times \left(\frac{100t}{D_o}\right)^3 \text{ but not greater than } \frac{200t\sigma}{3{\cdot}5D_o} \quad \ldots (3.11a)$$

c) In all other cases

$$t = \frac{D_o}{100}\left[0{\cdot}075p \cdot \frac{L}{D_o} \cdot K\right]^{\frac{2}{5}} \quad \ldots (3.12)$$

$$\text{or } p = \frac{13{\cdot}3\left(\frac{100t}{D_o}\right)^{\frac{5}{2}}}{\frac{L}{D_o} \cdot K} \quad \ldots (3.12a)$$

3.3.3.3 *Thickness of spherical shells under external pressure* — The thickness of spherical shells under external pressure is given by equation 3.13:

$$t = \frac{pD_o}{80\sigma} \quad \ldots (3.13)$$

$$\text{or } p = \frac{80\sigma t}{D_o} \quad . (3.13a)$$

3.3.3.4 *Stiffening rings*

a) *General* — Stiffening rings are generally used with cylindrical shells subjected to external pressure. They extend around the circumference of the shell and may be located on the inside or the outside of the shell.

The following notation has been used in the formulae given:

I_s = moment of inertia in cm⁴ of the ring section around an axis extending through the centre of gravity and parallel to the axis of the shell. For a stiffening ring, welded to the shell all around, a part of the shell, equal to $4t$ may be included in the moment of inertia when calculating the stiffening ring;

p = design pressure in kgf/cm²;

L_s = length between the centres of two adjacent stiffening rings in mm;

d = diameter through the centre of gravity of the section of an externally located stiffening ring or the inner diameter of the shell in the case of an internally located stiffening ring in mm; and

K = the ratio of the elastic modulus of the material at the design metal temperature to the room temperature elastic modulus (*see* Tables 3.1, 3.2, 3.3 and 3.4 for values of E at different temperatures).

b) The moment of inertia of the stiffening ring I_s shall not be less than that calculated by the formula.

$$I_s = 7 \times 10^{-6}\, pL_s d^3 K \quad \ldots (3.14)$$

c) Stiffening rings shall extend completely around the circumference of the shell. Joint between the ends or sections in the same ring or between adjacent portions shall be made so that the required moment of inertia of the ring is maintained (*see* Fig. 3.1).

When gaps and recesses are provided in the stiffening ring as in Fig. 3.1 it shall be

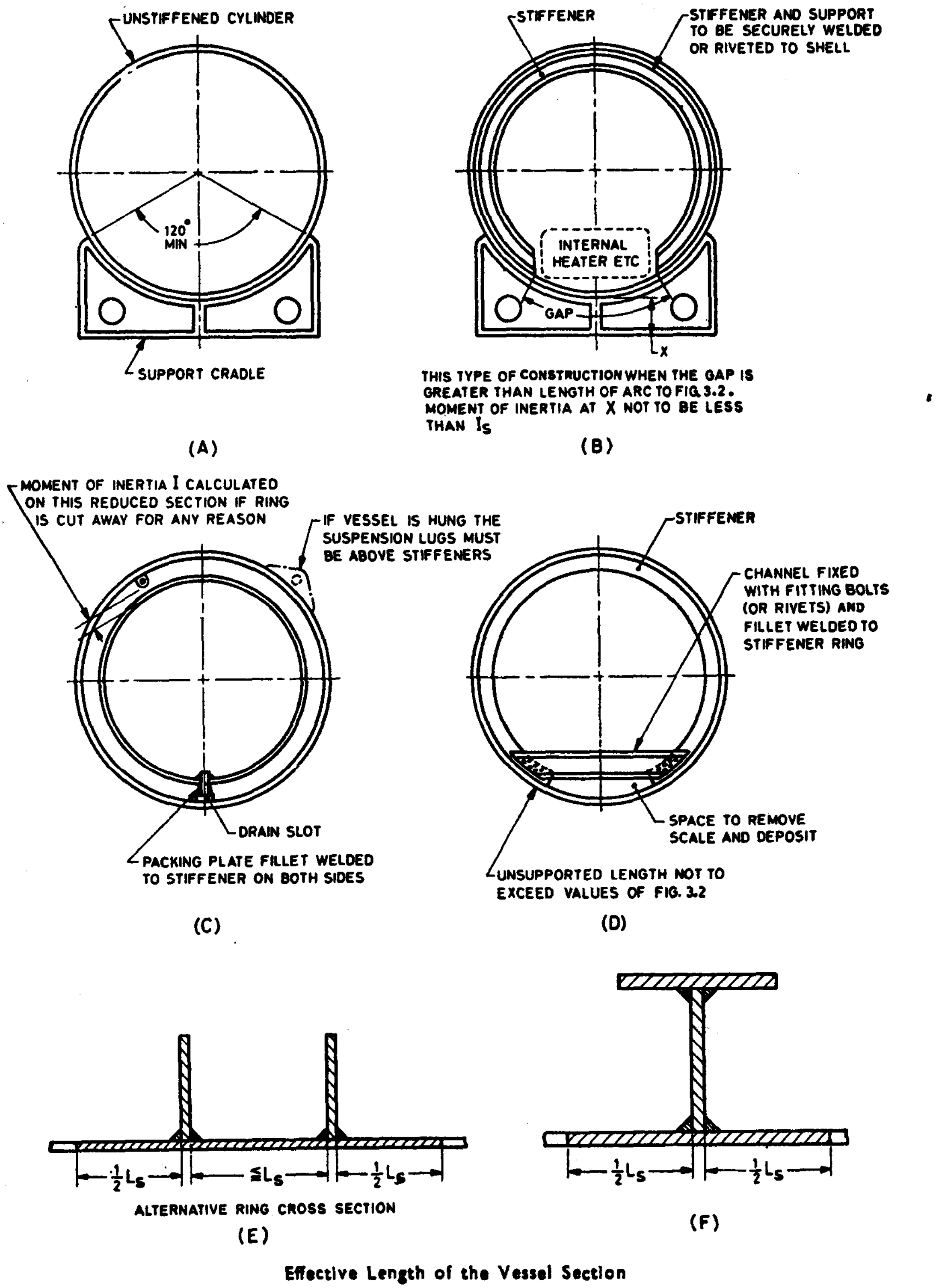


FIG. 3.1 STIFFENING RINGS FOR CYLINDRICAL VESSELS SUBJECT TO EXTERNAL PRESSURE

suitably reinforced so that the required moment of inertia is maintained.

However, if the gap in the stiffening ring does not exceed the value calculated from Fig. 3.2, reinforcement for the stiffener ring need not be provided.

Reinforcement for the stiffener ring also need not be provided if in case of gaps in adjacent stiffening rings, the length of the unsupported shell arc does not exceed 60° and the gaps in adjacent rings are staggered 180°.

d) Stiffening rings may be attached to the shell by welding or brazing or by any other method of attachment suitable for the material of construction. Brazing may be used when the vessel is not to be stress-relieved later.

The welding may be continuous or intermittent. In the case of intermittent welds:

1) the welds on either side of the ring shall overlap at least by 10 mm for stiffening rings situated on the outisde, and

2) the welds on either side of the ring shall be at least equal to one-third the circumference of the vessel in length, for stiffening rings situated on the inside.

e) Rings for supporting trays, plates, etc, in fractionating columns or similar constructions may be used as stiffening rings provided they are adequate for the duty.

3.3.3.5 *Thickness of tubes, and pipes when used as tubes under external pressure* — This shall be determined from the chart on page 18.

The thickness as determined from the graph shall be increased when necessary to meet the following requirements:

a) Additional wall thickness should be provided when corrosion, erosion or wear due to cleaning operations is expected.

b) Where tube ends are threaded, additional wall thickness is to be provided in the amount of 0·8 p (where p is the pitch in mm).

Note — The requirements for rolling, expanding, or otherwise seating tubes in tube plates may require additional wall thickness and careful choice of materials because of possible relaxation due to differential expansion stresses.

3.4 Domed Ends

3.4.1 *General* — Domed ends of hemispherical, semi-ellipsoidal or dished shape shall be designed in accordance with the requirements of **3.4.5** and **3.4.6**. The calculated thickness shall be increased, if necessary, to meet the requirements of **3.1** and **3.2**.

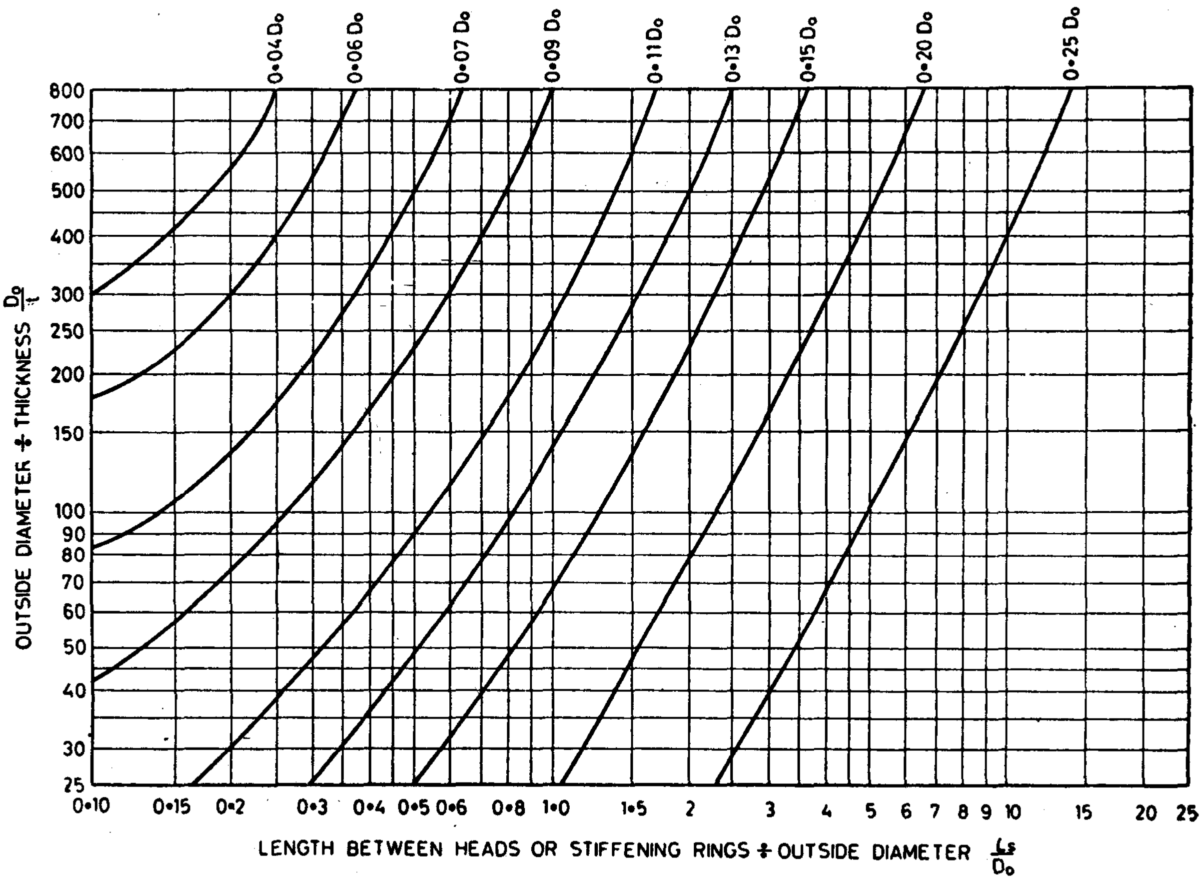


Fig. 3.2

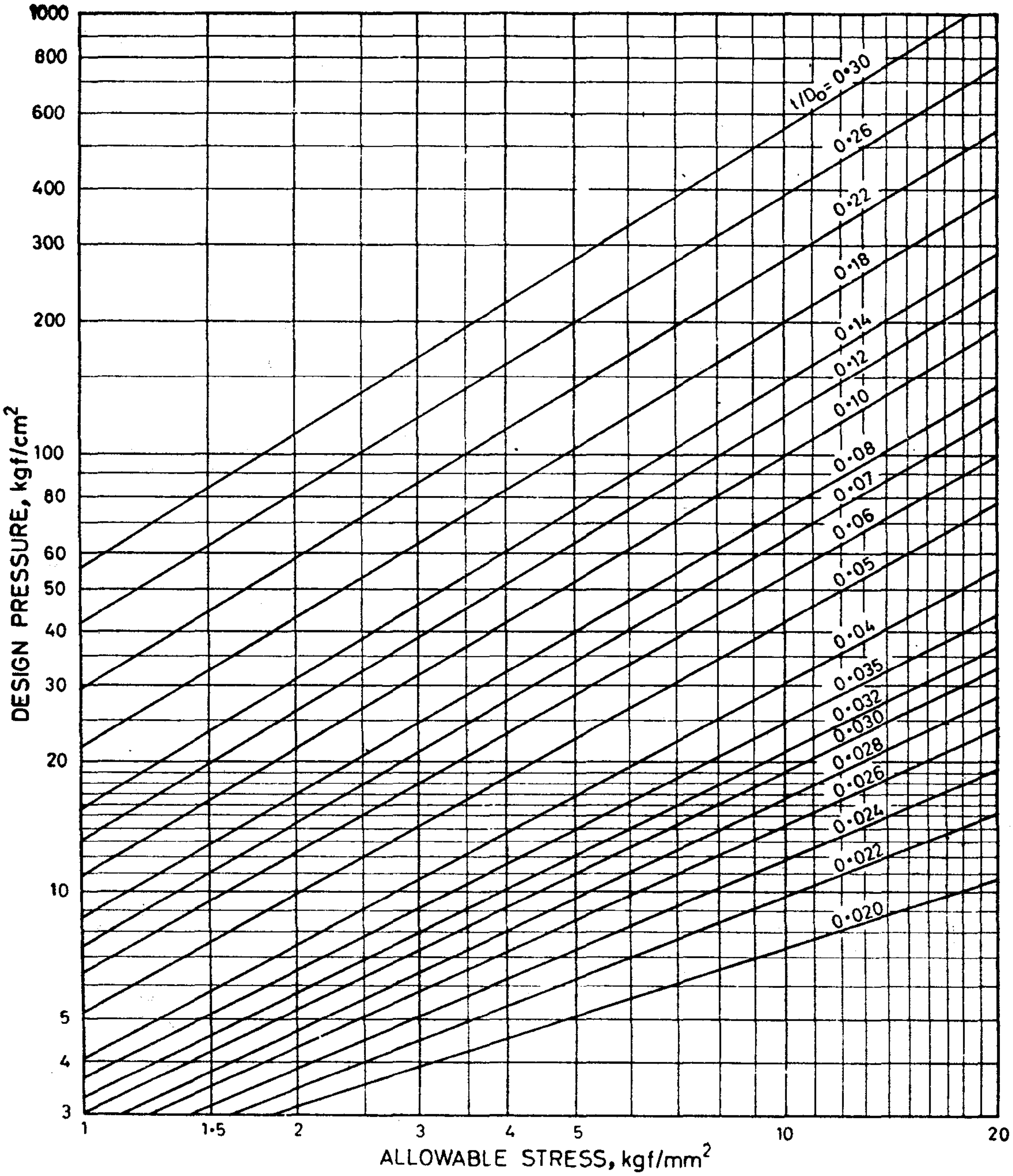


CHART FOR DETERMINING WALL THICKNESS OF TUBES UNDER EXTERNAL PRESSURE

3.4.2 *Limitations of Shape* — Ends shall conform to one of the following shapes (*see* IS : 4049-1968*):

a) Hemispherical (*see* Fig. 3.3A).

b) Semi-ellipsoidal (*see* Fig. 3.3B).

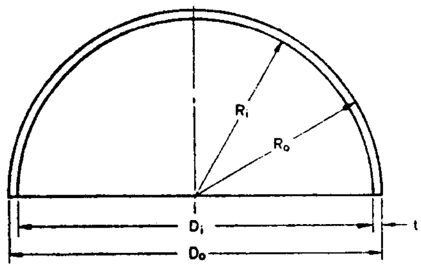
The ratio of major axis to minor axis should not be greater than 2·6 :1.

c) Dished and flanged (*see* Fig. 3.3C):

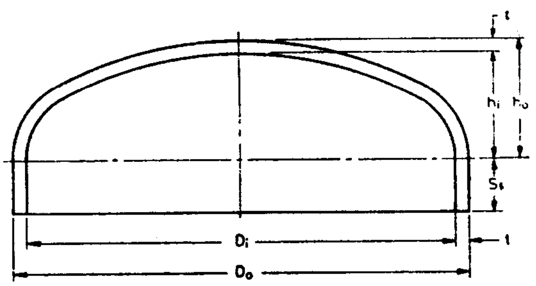
1) The inside radius of dishing R_i shall be not greater than the outside diameter D_o, and

2) The inside corner radius r_i shall preferably be not less than 10 percent of the inside diameter and in no case less than 6 percent nor less than $3t$.

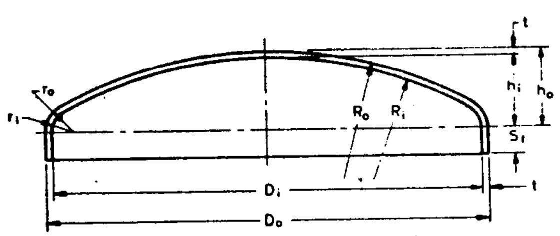
*Specification for formed ends for tanks and pressure vessels.



(A) Hemispherical Ends



(B) Semi-Ellipsoidal Ends



(C) Dished and Flanged Ends

FIG. 3.3 DOMED ENDS

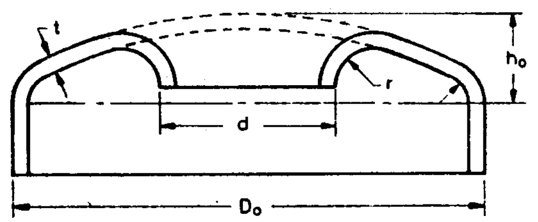


FIG. 3.4

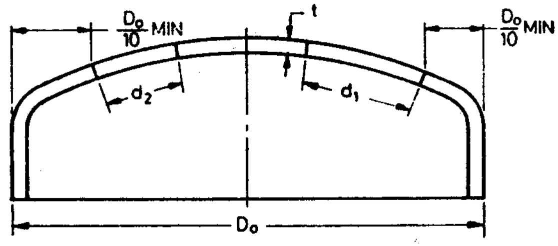


FIG. 3.5

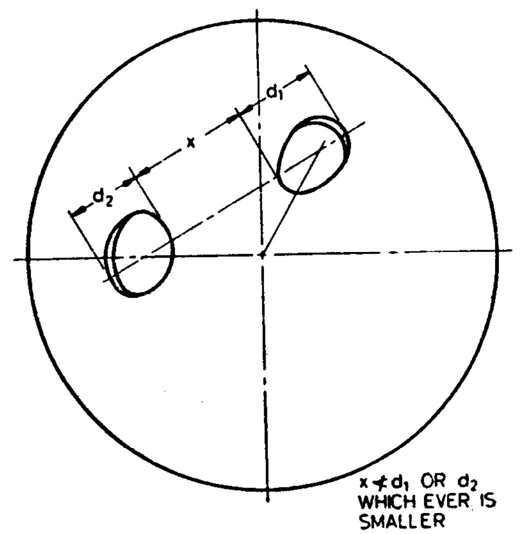


FIG. 3.6

FIG. 3.4-3.6 TYPICAL UNREINFORCED OPENINGS

3.4.3 *Openings in Ends*

3.4.3.1 Holes cut in domed ends shall be circular, elliptical or obround. Openings having a diameter exceeding 0·5 D_o shall be subject to special consideration. The radius of flanging r of flanged-in openings (*see* Fig. 3.4) shall be not less than 25 mm.

NOTE — An obround opening is one which is formed by two parallel sides and semi-circular ends.

3.4.3.2 *Uncompensated openings* — Flanged-in and other openings shall be arranged so that the distance from the edge of the end is not less than that shown in Fig. 3.5. In all cases the projected width of the ligament between any two adjacent openings shall be at least equal to the diameter of the smaller opening as shown in Fig. 3.6.

3.4.3.3 *Compensated openings* — Openings, where compensation is provided otherwise than by general thickening of the end (over and above that required for an unpierced end), shall comply with the requirements of **3.8**. Ends containing only openings compensated in accordance with **3.8** shall be regarded as plain ends for the purposes of applying Fig. 3.7.

3.4.4 *Notation* — The following notation has been employed:

t = minimum calculated thickness of the end in mm;

p = design pressure in kgf/cm²;

D_1, D_o = inner and outer diameters of the end in mm;

h_E = effective outside height of the end in mm;

where $h_E = h_o$ or $\frac{D_o^2}{4R_o}$ or $\sqrt{\frac{D_o r_o}{2}}$ whichever is the least

h_1, h_o = inside and outside height of the end in mm;

r_1, r_o = inside and outside knuckle (corner) radius in mm;

R_i, R_o = inner and outer crown radius in mm;

f = allowable stress value in kgf/mm²;

J = weld joint factor for any welded seam in the end including circumferential end-to-shell seam in the case of ends having no straight flange;

= 1·0 for ends made from one plate and attached to shell with a straight flange;

d = diameter of the largest uncompensated opening in the head. In the case of an elliptical opening the major axis of the ellipse in mm;

C = a shape factor obtained from Fig. 3.7; and

S_f = length of the straight flange.

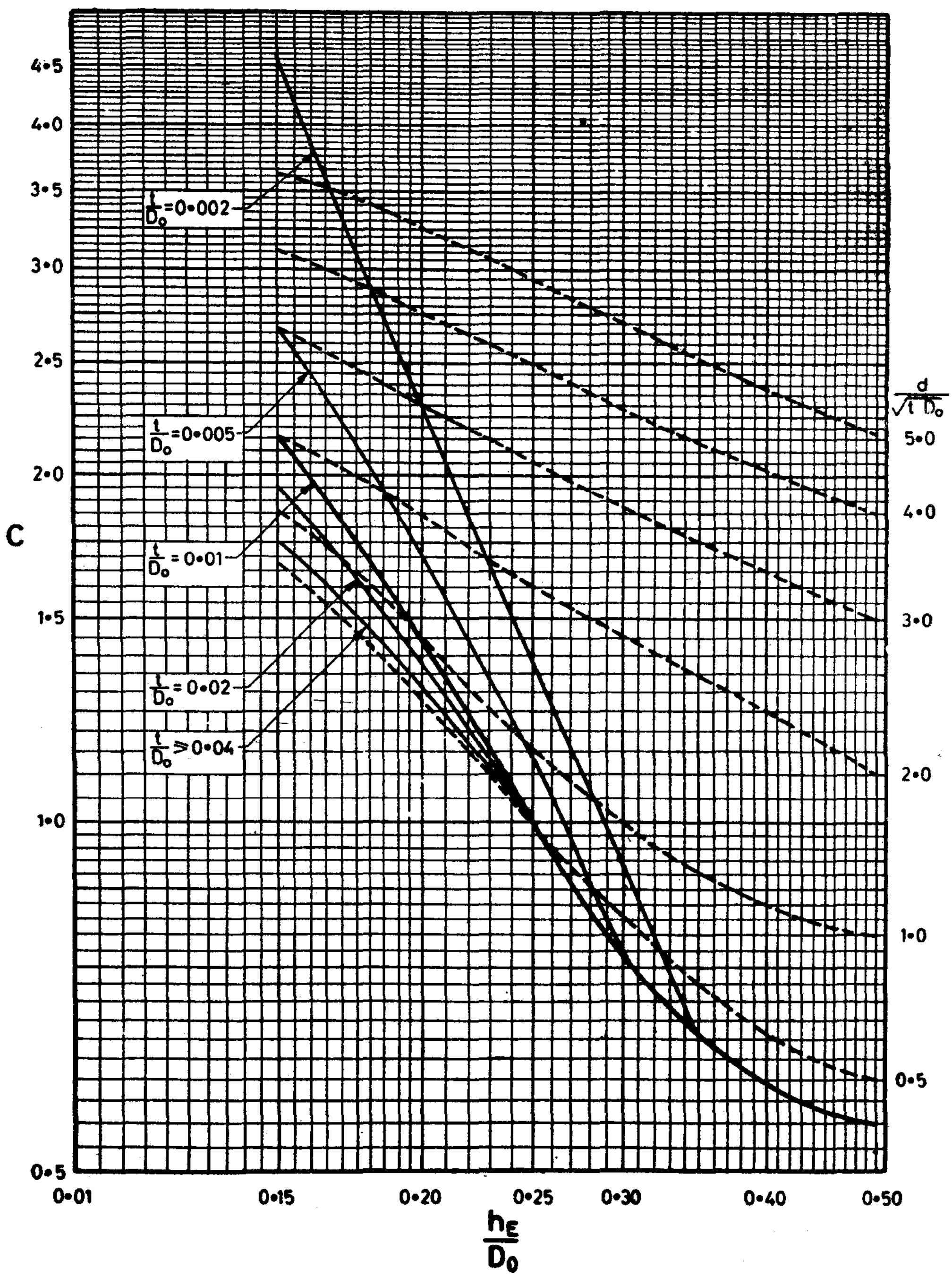


FIG. 3.7 SHAPE FACTOR FOR DOMED ENDS

3.4.5 *Thickness of Ends Concave to Pressure* — The thickness of the ends shall be determined by the equation:

$$t = \frac{pD_0C}{200fJ} \quad \ldots \quad \ldots \quad (3.15)$$

$$\text{or } p = \frac{200fJt}{D_0C} \quad \ldots \quad \ldots \quad (3.16)$$

NOTE — The external height of dishing h_0 may be determined from equation 3.17 in the case of ends of partially spherical form:

$$h_0 = R_0 - \sqrt{\left(R_0 - \frac{D_0}{2}\right) \times \left(R_0 + \frac{D_0}{2} - 2r_0\right)} \ldots (3.17)$$

NOTE 1 — In the case of ends containing no uncompensated openings, read C from full curves $t/D_0 = 0{\cdot}002$ to $t/D_0 = 0{\cdot}04$ interpolating as necessary.

NOTE 2 — In the case of ends containing uncompensated openings, read C from broken lines curves $d\sqrt{t.D_0} = 5{\cdot}0$ to $d\sqrt{t.D_0} = 0{\cdot}5$ interpolating as necessary. In no case shall C be taken as smaller than the value for similar unpierced end.

3.4.6 *Thickness of Ends Convex to Pressure*

3.4.6.1 *Spherically dished ends* — The thickness of the ends dished to partially spherical form shall be greater of the following thicknesses:

a) The thickness of an equivalent sphere, having a radius R_0 equal to the outside crown radius of the end, determined in accordance with **3.3.3.3**.

b) The thickness of the end under an internal pressure equal to 1·2 times the external pressure.

3.4.6.2 *Ellipsoidal ends* — The thickness of ends of a true semi-ellipsoidal shape shall be greater of the following thicknesses:

a) The thickness of an equivalent sphere, having a radius R_0 calculated from the values of $\frac{R_0}{D_0}$ in Table 3.5, determined in accordance with **3.3.3.3**.

b) The thickness of the end under an internal pressure equal to 1·2 times the external pressure.

3.4.7 *Constructional Details* — Typical permitted connections between ends and shells are shown in Table 6.2.

3.5 Conical Ends

3.5.1 *General* — Conical ends and conical reducing sections (*see* Fig. 3.8 and Fig. 3.9) shall be designed in accordance with the following formulae. The calculated thickness shall be increased, if necessary, to meet the requirements of **3.1** and **3.2**.

Conical ends may be constructed of several ring sections of decreasing thickness as determined by the corresponding decreasing diameter.

3.5.2 *Notation* — The following notations have been used in the formulae:

t = minimum calculated thickness of conical section or end in mm;

p = design pressure in kgf/cm²;

f = allowable stress in kgf/mm² determined in accordance with **2.2**;

J = weld joint factor;

D_k = inside diameter of conical section or end at the position under consideration (*see* Fig. 3.8) in mm;

D_e = outside diameter of conical section or end (*see* Fig. 3.8) in mm;

r_1 = inside radius of transition knuckle which shall be taken as 0·01 D_k in the case of conical sections without knuckle transition in mm;

$\alpha, \alpha_1, \alpha_2$ = angles of slope of conical section (at the point under consideration) to the vessel axis (*see* Fig. 3.8);

ψ = difference between angle of slope of two adjoining conical sections (*see* Fig. 3.8);

C = a factor taking into account the stress in the knuckle (*see* Table 3.6); and

L = distance, from knuckle or junction within which meridional stresses determine the required thickness (*see* Fig. 3.8) in mm.

$$0{\cdot}5\sqrt{\frac{D_e.t}{\cos\psi}}$$

3.5.3 *Conical Ends Subject to Internal Pressure* — The stresses in the knuckle or in the circumferential seam at the wide end of the cone acting in a meridional direction are predominantly bending stresses and the stresses acting in a circumferential direction are predominantly membrane stresses. Both these factors are taken into account in turn in equations 3.18 and 3.19. The greater of the two wall thicknesses calculated is chosen. For shallow cones, the thickness may be determined by the method given in (c) of this clause below, even though the resulting wall thickness may be less than those determined by the equations 3.18 and 3.19:

a) *Thickness of knuckle or conical section in junction* — The thickness of cylinder and conical section within distance L from the junction shall be determined by:

$$t = \frac{pD_eC}{200fJ} \quad \ldots \quad (3.18)$$

This thickness of the knuckle or junction shall however be not less than those given by equations 3.19 and 3.20.

If the distance of a circumferential seam from the knuckle or junction is not less than L then J shall be taken as 1·0, otherwise J shall be the weld joint factor appropriate to the circumferential seam.

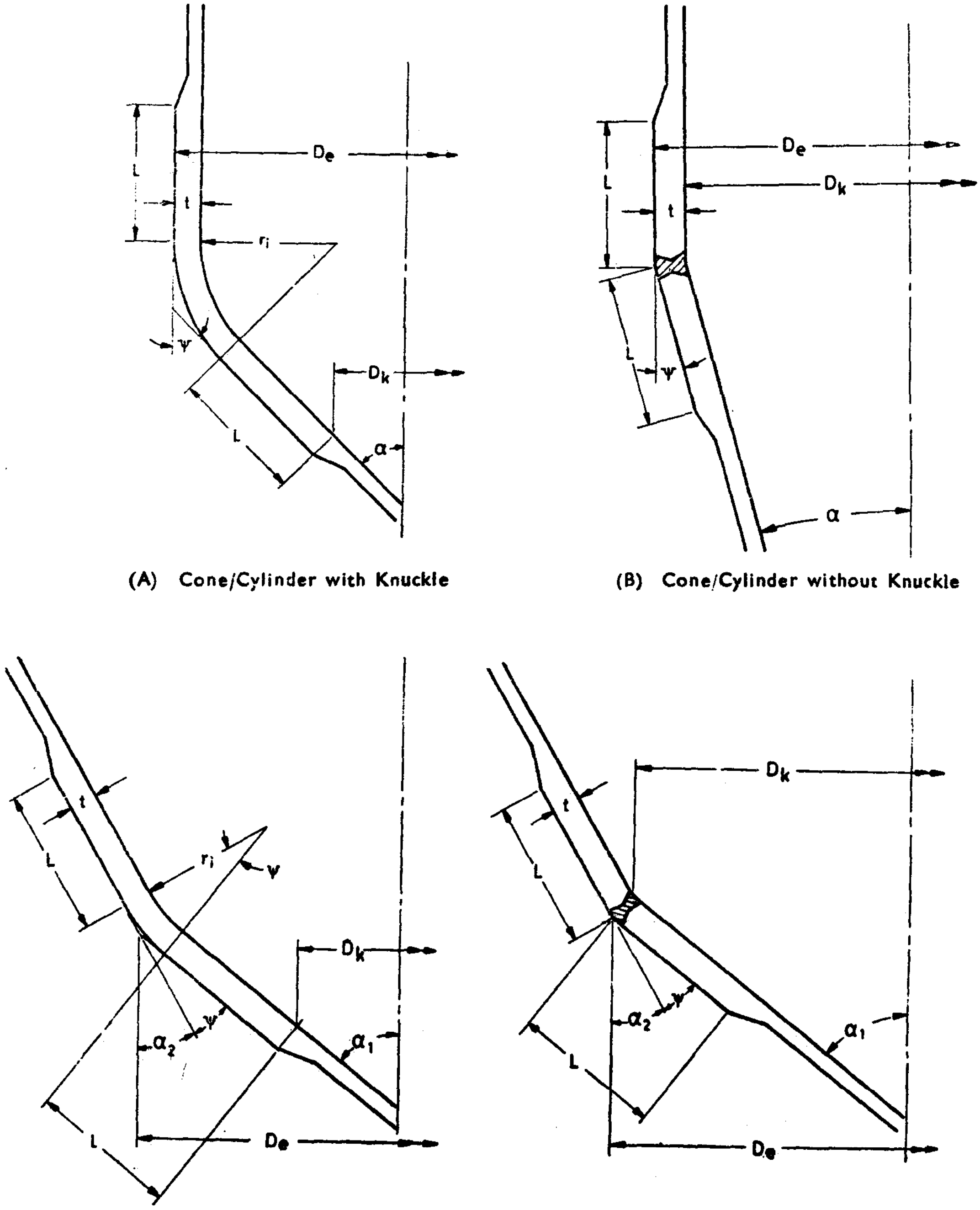
b) *Thickness of conical section away from junction* — The thickness of those parts of conical sections not less than a distance L away

TABLE 3.5 VALUES OF $\frac{R_o}{D_o}$ AS A FUNCTION OF $\frac{h_o}{D_o}$

(*Clause* 3.4.6.2)

$\frac{h_o}{D_o}$	=	0·167	0·178	0·192	0·208	0·227	0·25	0·278	0·313	0·357	0·417	0·50
$\frac{R_o}{D_o}$	=	1·36	1·27	1·182	1·08	0·99	0·90	0·81	0·73	0·65	0·57	0·50

Note — The intermediate values may be obtained by interpolation.



(A) Cone/Cylinder with Knuckle

(B) Cone/Cylinder without Knuckle

(C) Cone/Cone with Knuckle

(D) Cone/Cone without Knuckle

Fig. 3.8 Typical Cone Shell Connections

from the junction with a cylinder or other conical section shall be determined by:

$$t = \frac{pD_k}{200fJ - p} \times \frac{1}{\cos\alpha} \quad \dots \quad (3.19)$$

c) *Shallow conical sections* — The thickness of conical sections having an angle of inclination to the vessel axis of more than 70° shall be determined by:

$$t = 0.5\,(D_e - r_i) \times \frac{\alpha}{900}\sqrt{\frac{p}{f}} \dots (3.20)$$

The lower of the values given by equations 3.19 and 3.20 shall be taken.

3.5.4 *Conical Ends Subject to External Pressure* — For a conical end or conical section (frustum) under external pressure, whether the end is of seamless or butt welded construction, the general provisions of **3.5.1** to **3.5.3** are applicable, except that the thickness shall be not less than as prescribed below:

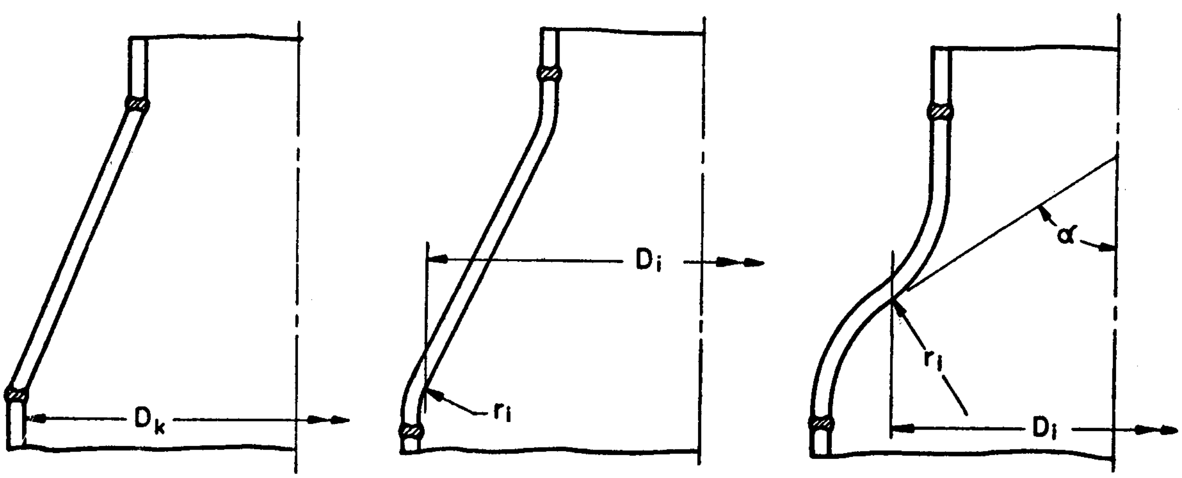
a) The thickness of a conical end or conical section under external pressure, when the angle of inclination of the conical section (at the point under consideration) to the vessel axis is not more than 70°, shall be made equal to the required thickness of cylindrical shell, in which the diameter is $D_e/\cos\alpha$ and the effective length is equal to the slant height of the cone or conical section, or slant height between the effective stiffening rings, whichever is less.

b) The thickness of conical ends having an angle of inclination to the vessel axis of more than 70° shall be determined as for a flat cover (*see* **3.6**).

TABLE 3.6 VALUES OF C AS FUNCTION OF ψ AND r_i/D_e

(*Clause* 3.5.2)

ψ \ r_i/D_e	0·01	0·02	0·03	0·04	0·06	0·08	0·10	0·15	0·20	0·30	0·40	0·50
10°	0·70	0·65	0·60	0·60	0·55	0·55	0·55	0·55	0·55	0·55	0·55	0·55
20°	1·00	0·90	0·85	0·80	0·70	0·65	0·60	0·55	0·55	0·55	0·55	0·55
30°	1·35	1·2	1·1	1·0	0·90	0·85	0·80	0·70	0·55	0·55	0·55	0·55
45°	2·05	1·85	1·65	1·5	1·3	1·2	1·1	0·95	0·90	0·70	0·55	0·55
60°	3·2	2·85	2·55	2·35	2·0	1·75	1·6	1·4	1·25	1·00	0·70	0·55
75°	6·8	5·85	5·35	4·75	3·85	3·5	3·15	2·7	2·4	1·55	1·00	0·55



(A) Cone Section (B) Cone Section with Transition Knuckles (C) Reversed Curve Section

FIG. 3.9 ALTERNATIVE FORMS OF OPENINGS IN DOMED ENDS FOR CASES WHEN d EXCEEDS $D/2$

3.5.5 *Constructional Details* — Connections between cylindrical shells and conical sections and ends shall preferably be by means of a knuckle transition radius. Typical permitted details are shown in Fig. 3.8. Alternatively conical sections and ends may be butt welded to cylinders without a knuckle radius when the change in angle of slope ψ between the two sections under consideration does not exceed 30°.

3.6 Unstayed Flat Heads and Covers

3.6.1 *General* — Flat covers and end plates shall be designed in accordance with the following formulae and the thickness shall be increased, if necessary, to meet the requirements of **3.1** and **3.2**.

3.6.1.1 *Notation* — The following notation has been used in the following formulae:

- a = short span of non-circular heads in mm;
- b = long span of non-circular heads or covers measured perpendicular to short span in mm;
- C = a factor depending upon the method of attachment to shell (*see* Table 3.7);
- D = diameter or short span measured as in Table 3.7;
- h_G = gasket moment arm equal to the radial distance from the centre line of the bolts to the line of gasket reaction in mm;
- L = perimeter of non-circular bolted heads measured along the centres of the bolt holes in mm;
- l = length of the flange of flanged heads in mm;
- p = design pressure in kgf/cm²;
- f = allowable stress value in kgf/mm²;
- t = minimum thickness of flat head or cover, exclusive of corrosion allowance in mm;
- t_r, t_s = required and actual thickness of the shell under design conditions, exclusive of corrosion allowance in mm;
- F_B = total bolt load in kgf; and
- Z = a factor for non-circular heads depending upon the ratio of short span to long span a/b (*see* Fig. 3.10).

3.6.2 *Thickness of Flat Heads and Covers*

3.6.2.1 The thickness of flat unstayed circular heads and covers shall be calculated by the following formula :

$$t = \frac{CD}{10}\sqrt{\frac{p}{f}} \qquad \ldots \qquad (3.21)$$

When the head or cover is attached by bolts causing an edge moment, the thickness t shall be calculated for both initial tightening and design conditions and the greater of the two values selected.

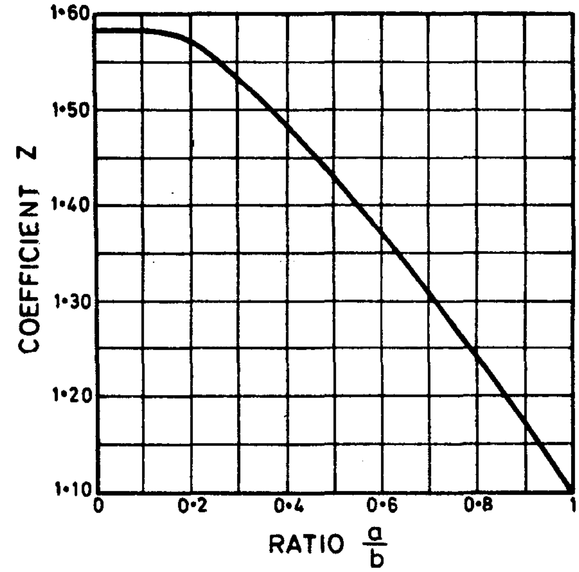


Fig. 3.10 Value of Coefficient Z for Non-circular Flat Heads

3.6.2.2 The thickness of non-circular heads and covers shall be calculated by the following formula :

$$t = \frac{CZa}{10}\sqrt{\frac{p}{f}} \qquad \ldots \qquad (3.22)$$

When the head or cover is attached by bolts causing an edge moment, the thickness t shall be calculated for both initial tightening and design conditions and the greater of the two values selected.

3.6.3 *Spherically Dished Covers and Quick Opening Closures*

3.6.3.1 *Spherically dished covers* — The thickness of spherically dished ends secured to the shell through a flange connection by means of bolts shall be calculated by:

$$t = \frac{3pD_i}{200fJ} \qquad \ldots \qquad (3.23)$$

provided that the inside crown radius R of the dished cover does not exceed 1·3 times the shell inside diameter D_i and the value of 100 t/R is not greater than 10.

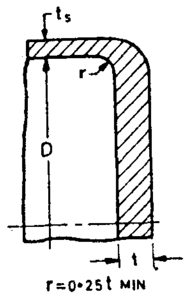
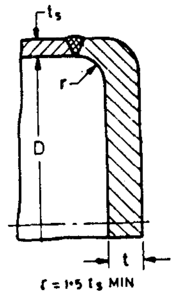
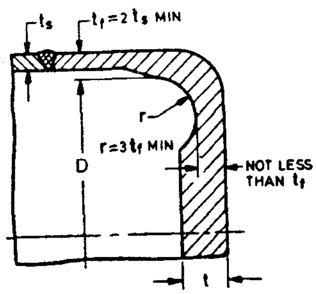
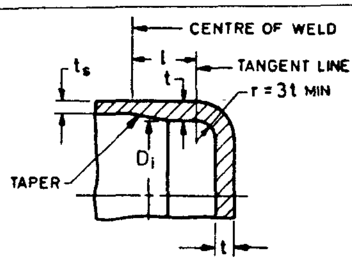
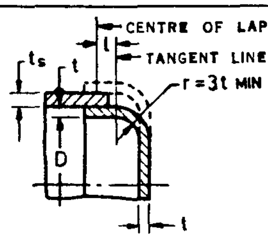
3.6.3.2 *Quick opening closures* — These shall be so designed that failure of anyone holding element cannot result in release or failure of all of the other holding elements. Closures of this type shall be so arranged that it may be determined at all times by usual examination that the holding devices are in good mechanical condition and that their locking elements when closed are in full engagement.

They shall be so designed that when the vessel is installed:

a) the closure and its holding elements are fully engaged in their intended operating position before pressure can be built up in the vessel, and

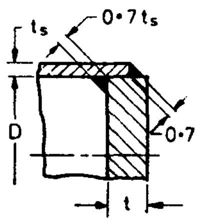
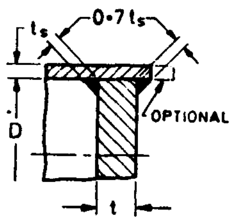
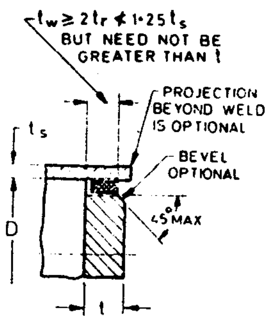
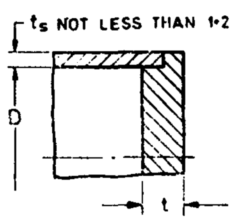
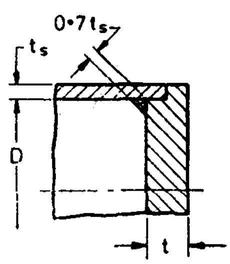
TABLE 3.7 VALUES OF *D* AND *C* FOR TYPICAL UNSTAYED FLAT HEADS

(*Clauses* 3.6.1 *and* 3.6.2)

Sl No.	Description	Typical Example	Remarks
1.	Forged heads	 (a)	$C=0{\cdot}5$
		 (b)	$C=0{\cdot}5$
		 (c)	$C=0{\cdot}45$
2.	Flanged flat heads butt welded to the vessel		$C = 0{\cdot}35$ when $l \geqslant \left(1{\cdot}1 - 0{\cdot}8\,\frac{t_s^2}{t^2}\right)\sqrt{D_i t}$ $r \geqslant 2t$ $D = D_i - r$ and taper is 1 : 4 $C = 0{\cdot}45$ when $r \geqslant 2t$ $D = D_i - r$ and taper is 1 : 4 $C = 0{\cdot}5$ when $D = D_i$ and $0{\cdot}25\,t \leqslant r < 2t$
3.	Heads lap welded or brazed to the shell		$C = 0{\cdot}45$ when $l \geqslant \left(1{\cdot}1 - 0{\cdot}8\,\frac{t_s^2}{t^2}\right)\sqrt{Dt}$ and $C = 0{\cdot}55$ in other cases

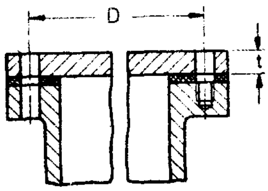
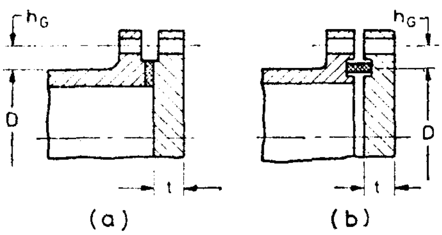
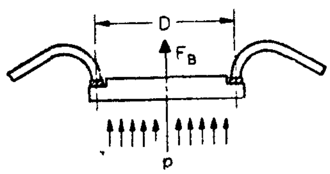
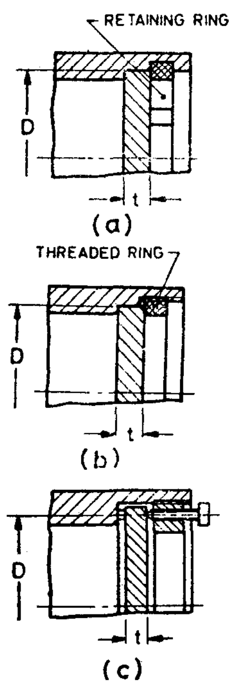
(*Continued*)

TABLE 3.7 VALUES OF *D* AND *C* FOR TYPICAL UNSTAYED FLAT HEADS — *Contd*

Sl No.	Description	Typical Example	Remarks
4.	Plates welded to the inside of the vessel	 (a)  (b)  (c)	$C = 0{\cdot}7 \sqrt{\frac{t_r}{t_s}}$ but not less than 0·55
5.	Plates welded to the end of the shell		$C = 0{\cdot}7$
6.	Plates welded to the end of the shell with an additional fillet weld on the inside		$C = 0{\cdot}7 \sqrt{\frac{t_r}{t_s}}$ but not less than 0·55

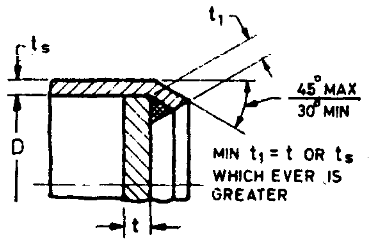
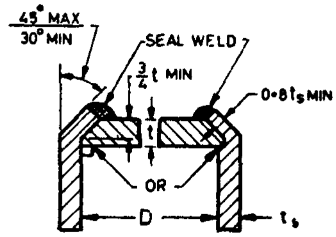
(Continued)

TABLE 3.7 VALUES OF *D* AND *C* FOR TYPICAL UNSTAYED FLAT HEADS — *Contd*

Sl No.	Description	Typical Example	Remarks
7.	Covers riveted or bolted with a full face gaskets to shells, flanges or side plates		$C = 0.42$
8.	Covers with a narrow face bolted flange joint		$C = \sqrt{0.31 + 190 \frac{F_B\, h_G}{p D^3}}$ where F_B is the bolt load
9.	Autoclave manhole covers $D \not> 610$ mm		$C = \sqrt{0.31 + 95 \frac{F_B}{p D^2}}$
10.	Plates inserted into the end of a vessel and held in place by a positive mechanical locking arrangement		All means of failures shall be resisted with a factor of safety of at least 4. Seal welds may be used if desired. $C = 0.55$

(*Continued*)

TABLE 3.7 VALUES OF *D* AND *C* FOR TYPICAL UNSTAYED FLAT HEADS — *Contd*

SL No.	DESCRIPTION	TYPICAL EXAMPLE	REMARKS
11.	Plates inserted into the vessel as shown and the end of the vessel crimped over $D \not> 450$ mm	 (a)  $\frac{t_s}{D} \nless \frac{p}{100f}$ or $\nless 0{\cdot}05$ and $p \not> 20f$ (b)	Crimping shall be done cold only when the operation will not injure the metal. In other cases crimping shall be done when the entire circumference of the cylinder is uniformly heated to the proper forging temperature for the material. Crimping angle shall not be less than 30° but need not exceed 45°. $C = 0{\cdot}7$

b) pressure tending to force the closure clear of the vessel will be released before the closure can be fully opened for access.

In case the requirements (a) and (b) are not satisfied in the design of the closure, provision shall be made so that devices to accomplish this can be added when the vessel is installed.

Vessels with quick-opening closures shall be installed with a pressure gauge or warning device and, in addition, with means which will prevent pressure being applied unless the cover and holding elements are in proper operating condition and prevent disengagement of the holding elements while there is pressure loading on the cover.

3.7 Stayed and Braced Plates

3.7.1 *General* — Plates which are braced by being connected to each other by means of stays, tubes, blocks, etc, shall be designed in accordance with the following formulae. Though the method of calculation used is primarily applicable to flat parallel plates, it may, when suitable, be applied to slightly inclined plates or surfaces which because of their smaller thickness than required under the clauses of this code are to be stayed as flat plates.

3.7.2 *Design*

3.7.2.1 Stays may be attached to the plate stayed by screwing, welding, expanding, bolting or by a combination of any of these methods.

3.7.2.2 Stays made up of more than one bar welded into the body, that is composite bars, shall not be used.

3.7.2.3 When the stays are of such long span that there is a possibility of undue sagging, consideration should be given to the support of the stays.

3.7.2.4 Stays shall not bear against the shell of the vessel except through the medium of a substantially continuous ring.

3.7.3 *Thickness of the Stayed and Braced Plates*

3.7.3.1 The thickness of the stayed and braced plates shall be calculated by the following formula:

$$t = \frac{CD}{10}\sqrt{\frac{p}{f}} \qquad \ldots (3.24)$$

where

t = minimum thickness of the plate in mm;

p = design pressure in kgf/cm²;

D = diameter of the largest circle in mm which may be inscribed between the supporting points of the plate (*see* Fig. 3.11);

f = allowable stress value in kgf/mm²; and

C = a factor depending on the mode of support and is given by Fig. 3.12A to 3.12F. When the plate is supported in different ways on the circumference of the inscribed circle of diameter D, a mean value is to be adopted for C.

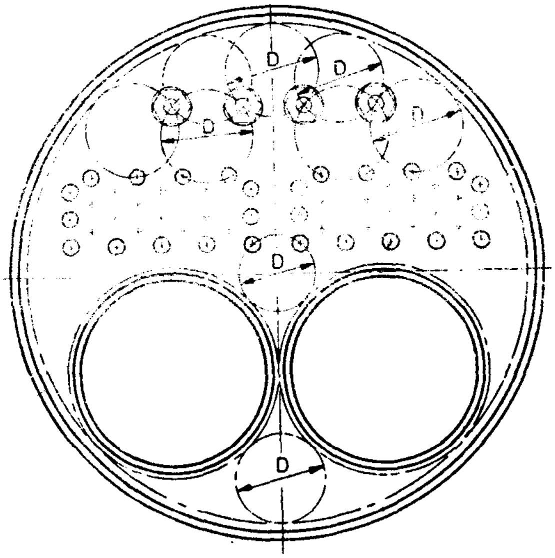


Fig. 3.11 Stayed Flat Plate

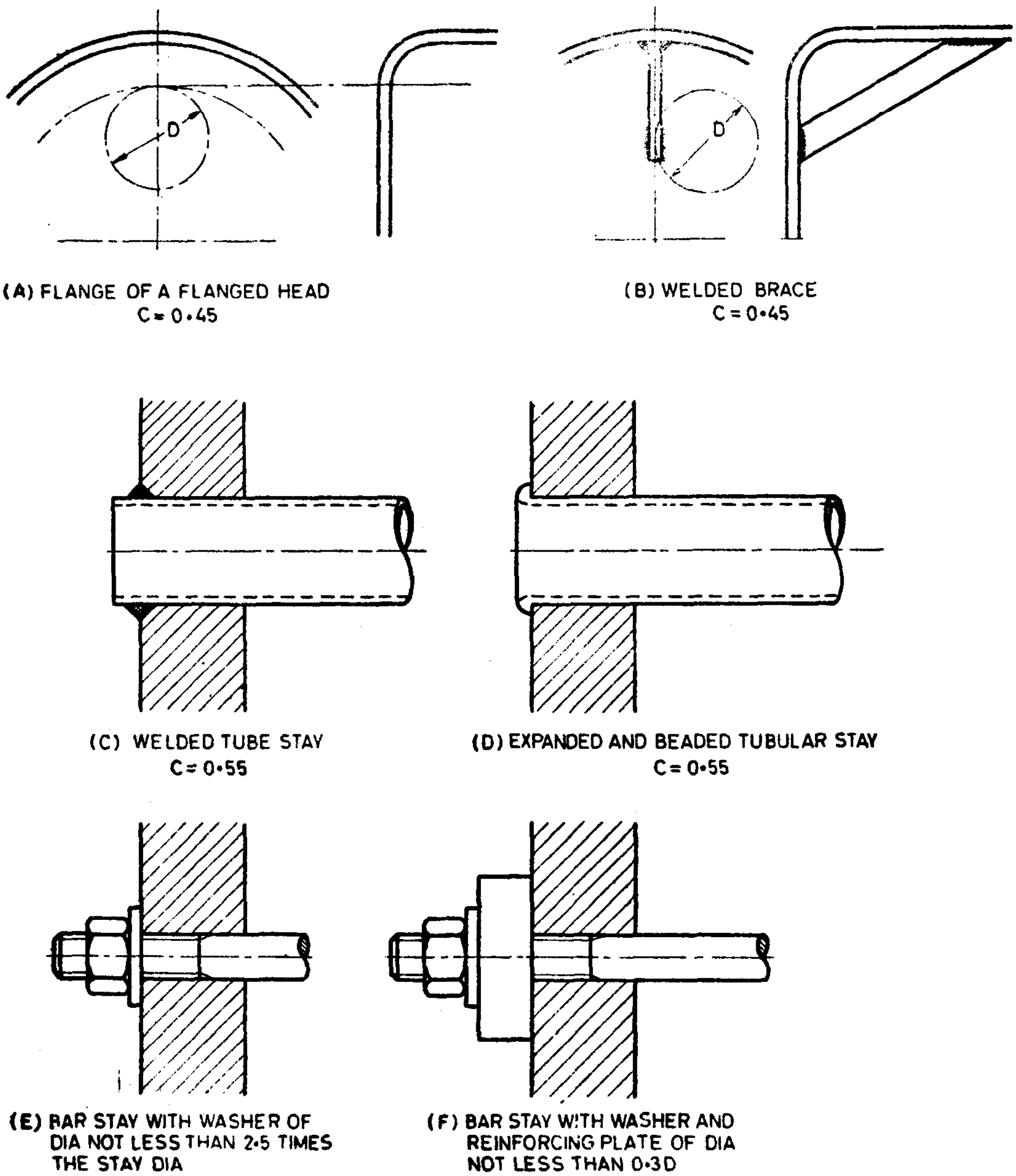


Fig. 3.12 Values of Co-efficient C Depending on the Type of Stay

3.8 Openings, Branches and Compensation

3.8.1 *General*

3.8.1.1 Openings in the shell or end plates of a vessel shall be circular, elliptical or obround with a ratio of major to minor inside diameter not exceeding 2.

3.8.1.2 It is preferable to locate all openings clear of welded seams.

3.8.2 *Limitation of Formulae*

3.8.2.1 The formulae and rules given here for the design of compensation around openings are intended to apply directly to openings and branch connections not exceeding:

a) one-third the inside diameter of the shell for cylindrical and spherical shells;
b) one-third the inside diameter of the conical section measured where the nozzle axis pierces the inner surface of the conical section, and for conical sections; and
c) one-half the outside diameter of the end for ends.

Compensation of larger openings should be the subject of special consideration and, if necessary, the adequacy of the proposed design should be demonstrated by means of model tests or hydraulic proof test in accordance with **8.4**.

In the case of large openings in ends, the use of a conical or reversed curve reduction piece (*see* Fig. 3.9) is recommended.

Details shown in Fig. 3.13A to 3.13E offer progressive reductions in stress concentration. This consideration is of particular significance in the case of services involving severe fluctuations in pressure or temperature (*see* Appendix E) or low temperature duties (*see* Appendix D).

3.8.2.2 The formulae and rules given here are not directly applicable to:

a) oblique nozzles when the angle between the axis of the nozzle and a line normal to the shell surface exceeds 15°, and
b) multiple openings or multiple branches where the axial distance is less than 1·5 times average diameter.

3.8.3 *Uncompensated Openings* — Isolated openings in cylindrical or conical shells or spheres having a diameter not exceeding that given by Fig. 3.14 subject to a maximum of 200 mm, do not require added compensation. For the limitations governing uncompensated openings in the ends, *see* **3.4.3**.

Openings spaced apart a distance not less than:

$$L = \frac{d(\,t_a/t_r\,)}{(\,t_a/t_r - 0{\cdot}95\,)} \qquad \ldots \qquad (3.25)$$

but in no case less than twice the diameter of the larger opening may be regarded as isolated openings.

where

L = distance between centres of any two adjacent openings in mm;

d = diameter of largest opening, in the case of an elliptical or obround opening the mean value of the two axes in mm;

t_a = actual thickness of vessel before corrosion allowance is added in mm;

t_r = required thickness of vessel putting $J = 1{\cdot}0$ before corrosion allowance is added in mm; and

K = a factor equal to $\dfrac{pD_o}{182 f t_a}$ (*see* Fig. 3.14A & B)

When K has a value of unity or greater, the maximum size of an unreinforced opening shall be 50 mm.

3.8.4 *Location of Compensated Openings in Ends* — Compensated openings in domed ends of semi-ellipsoidal or dished shape should preferably be so located that the outside of any attachment or the edge of any additional compensation will not be a greater distance from the centre of the end than 40 percent of the outside diameter of the end. In cases where this is not practicable the vessels shall be subjected to a hydraulic proof test (*see* **8.4**) except where similar vessels have proved the adequacy of the design by satisfactory operation under comparable conditions over a substantial period (*see* **3.4.3.2** for uncompensated openings).

3.8.5 *Compensated Openings in Shells and ends*

3.8.5.1 *General* — At all planes through the axis of the opening normal to the vessel surface the cross-sectional area requirements for compensation as calculated below shall be satisfied:

Material in added compensation, or in a branch, should have similar mechanical and physical properties to that in the vessel shell or end. Where material having a lower allowable stress than that of the vessel shell or end is taken as compensation its effective area shall be assumed to be reduced in the ratio of the allowable design stresses at the design temperature. No credit shall be taken for the additional strength of material having a higher stress value than that in the shell or end of the vessel.

3.8.5.2 *Calculation of compensation required*

a) *Area required to be compensated* — The total cross-sectional area of compensation, A, required in any given plane for a vessel under internal pressure shall be not less than:

$$A = d.t_r \qquad \ldots \qquad \ldots \quad (3.26)$$

where

d = nominal internal diameter of the branch plus twice the corrosion allowance in mm (*see* Fig. 3.15 and 3.16),

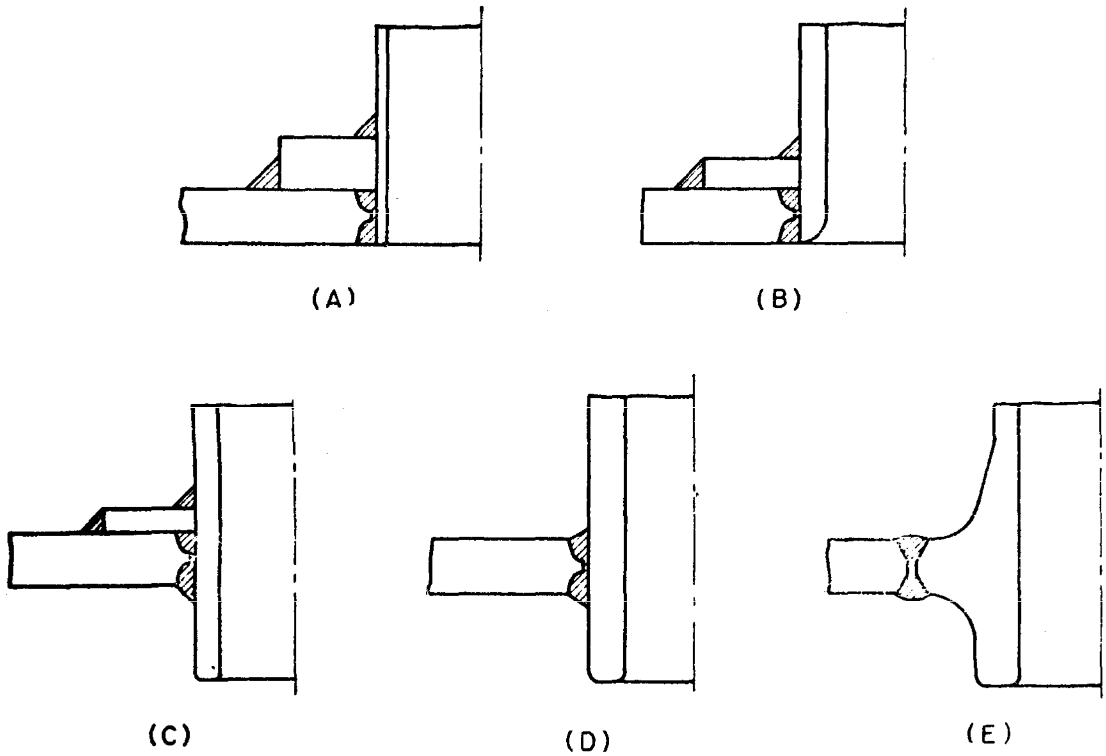


Fig. 3.13 Typical Compensated Openings

t_r = thickness, in mm, of an unpierced shell or end calculated from equations 3.1 and 3.3 and if the opening is located clear of any welded seam $J = 1{\cdot}0$ except that:

1) *For dished and flanged and hemispherical ends* — When the opening and its compensation are located entirely within the spherical portion of a dished end, t_r is the thickness required for a sphere having a radius equal to the spherical portion of the end.

2) *For semi-ellipsoidal ends* — When the opening and its compensation are in an ellipsoidal end and are located entirely within a circle having a radius, measured from the centre of the end, of 0·40 of the shell diameter, t_r is the thickness required for a sphere having a radius R, derived from the following:

h_i/D_i	0·167	0·178	0·192	0·207
R_i/D_i	1·36	1·27	1·18	1·08
h_i/D_i	0·227	0·25	0·277	0·312
R_i/D_i	0·99	0·90	0·81	0·73
h_i/D_i	0·357	0·40	0·45	0·50
R_i/D_i	0·65	0·59	0·54	0·50

where

h_i = depth of dishing of end plate measured internally (*see* Fig. 3.3) in mm,

D_i = inside diameter of end plate in mm, and

R_i = inside radius of equivalent sphere in mm.

3) When the opening is in a cone, t is the thickness required for a cone of diameter D_K where the centre line of the opening pierces the inside surface of the cone.

b) *Material available for compensation* — Only material located within the rectangle *wxyz* (*see* Fig. 3.15) shall be deemed effective compensation.

1) The portion of the shell or end available for compensation shall be taken as:

$$A_s = d(t - t_r - c) \quad \ldots (3.27)$$

2) The portion of the branch external to the vessel available for compensation shall be taken as:

$$A_o = 2H_1 (t - t_r - c) \quad (3.28)$$

3) The portion of the branch inside the vessel available for compensation shall be taken as:

$$A_i = 2H_2 (t - 2C) \quad \ldots (3.29)$$

where

A_s = area of portion of shell or end which is effective as compensation mm^2;

A_o' = area of portion of branch pipe external to vessel which is effective as compensation in mm^2;

t = actual thickness of part, that is, shell, end or branch, under consideration, in mm;

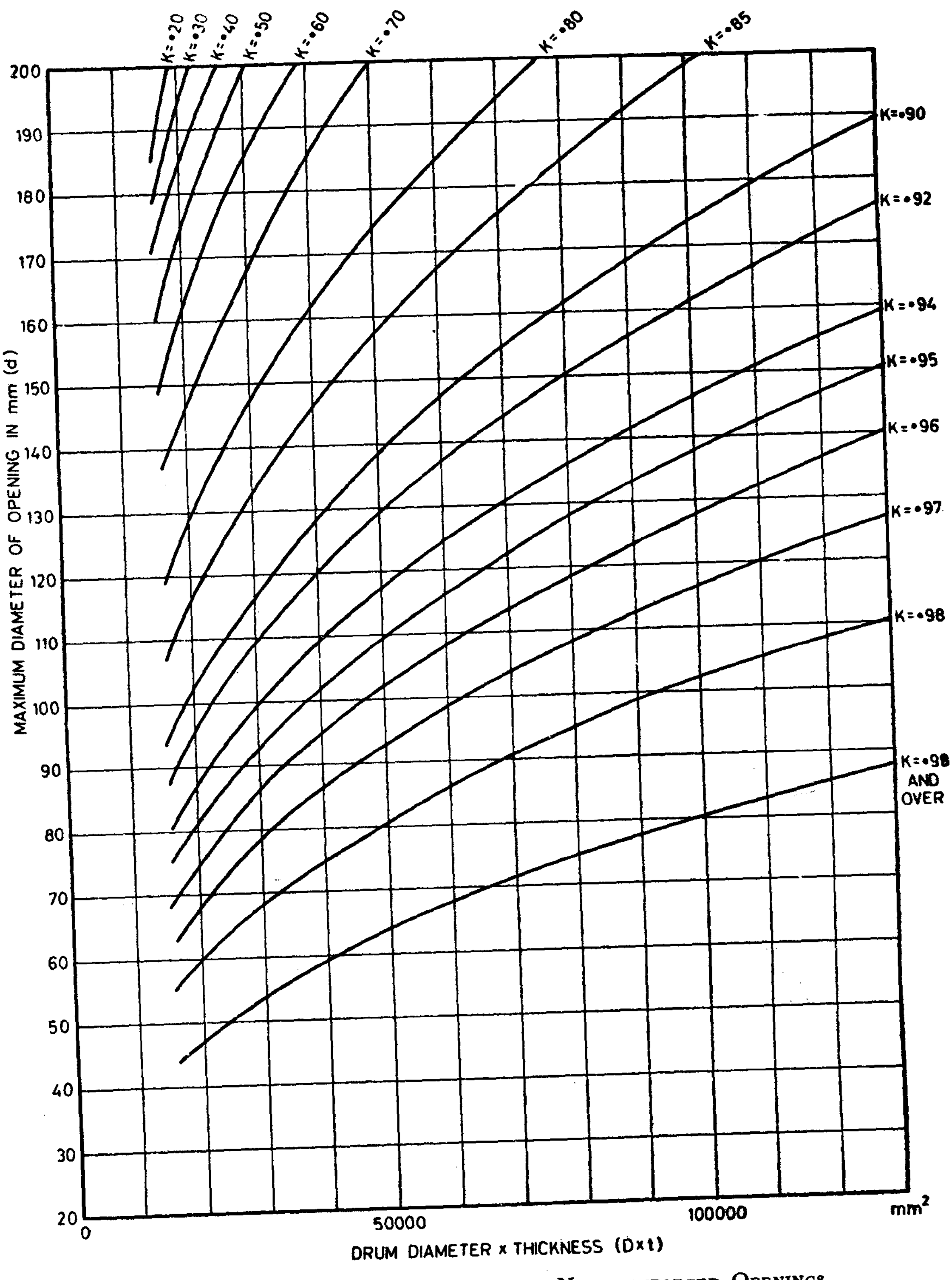


FIG. 3.14A MAXIMUM DIAMETER OF NON-REINFORCED OPENINGS

t_r = minimum required thickness of part under consideration putting $c = 0$, in mm;

H_1 = height of effective compensation in branch wall external to vessel, measured from outside surface of compensation ring or vessel wall, in mm, the lesser of $\sqrt{d(t-c)}$ and the actual height of the fitting; and

H_2 = height of any portion of branch pipe projecting inside vessel and effective as compensation, measured from the inside surface of vessel or compensation ring, in mm, the lesser of $\sqrt{d(t-2C)}$ and the actual height of the fitting;

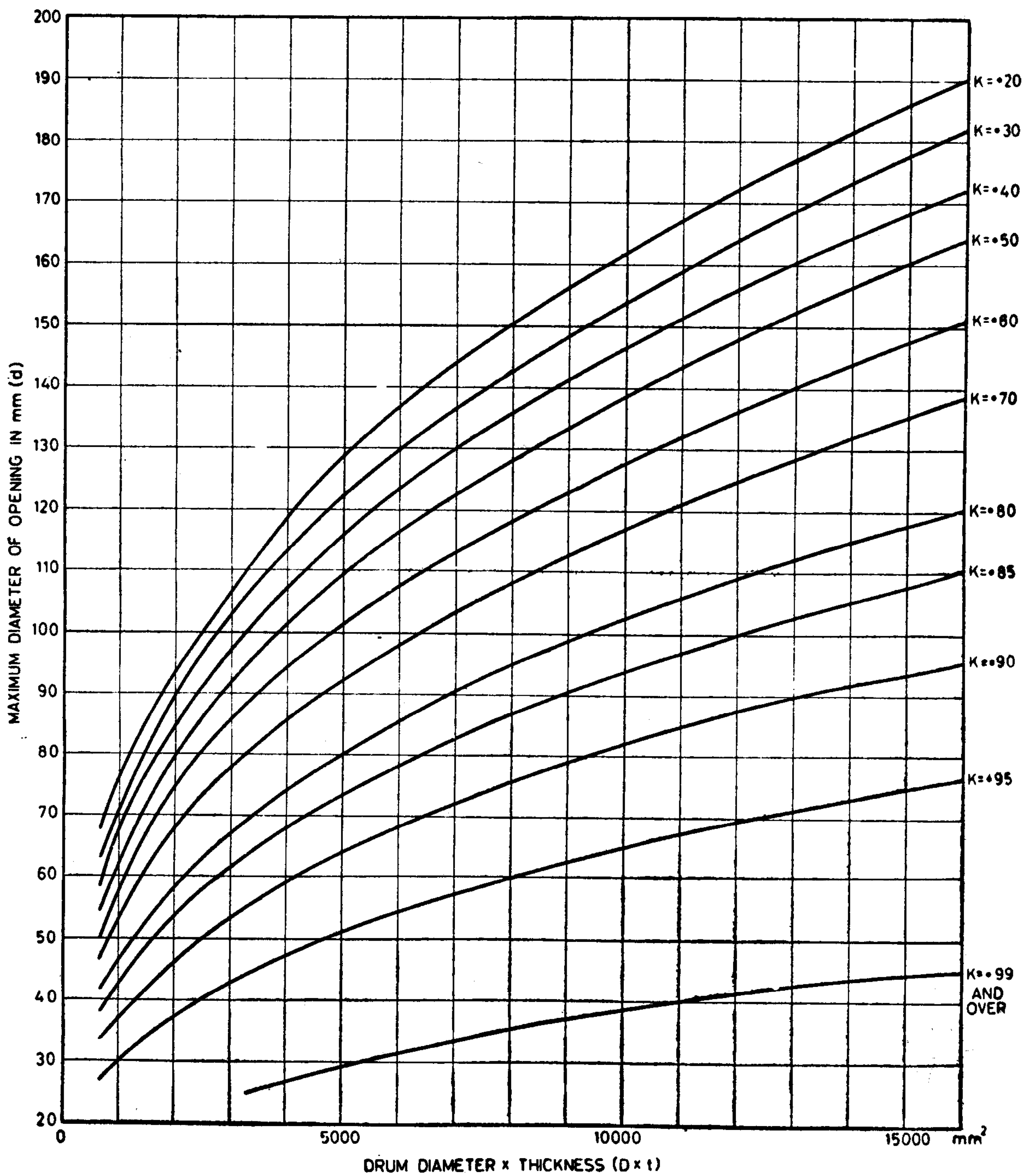


Fig. 3.14B Maximum Diameter of Non-reinforced Openings

A_i = area of portion of branch pipe inside vessel which is effective compensation:

c = corrosion allowance in mm; and

d = inside diameter of branch in corroded condition, in mm.

Where the calculated value of A is greater than ($A_s+A_o+A_i$), additional compensation equal to $A-(A_s+A_o+A_i)$ shall be provided.

c) *Compensation of flanged-in openings* — (*see* **3.4.3**). Compensation for openings of this type, as shown in Fig. 3.17, shall be calculated as above except that:

1) The depth of flanging which may be counted as compensation shall be in accordance with equation 3.30:

$$H_3 = \sqrt{W(t-c)} \quad \ldots (3.30)$$

where

H_3 = depth of flanging, in mm, allowed as compensation and as shown in Fig. 3.17.

NOTE — H_3 for a cylindrical shell is measured at the side of the minor axis, and for a domed end at the side of the major axis.

W is the maximum width of opening in mm as shown in Fig. 3.17. Where the opening is cut in a cylindrical shell, W shall be the minor axis and shall be placed parallel to the axis of the vessel. Where the opening is cut in a domed or flat end, W shall be the major axis.

2) The area of compensation necessary shall be determined by equation 3.31:

$$A = W_m . t \quad \ldots (3.31)$$

where

A = area of compensation required, in mm²;

W_m = mean width of opening as shown in Fig. 3.17 measured parallel to the longitudinal axis of the vessel in the case of openings in shells, or, in the case of openings in end plates, measured along the major axis of the opening, in mm; and

t_r = calculated thickness in mm, and, if the opening is located clear of a welded joint, $J=1{\cdot}0$.

3) The full thickness of the flanging, less corrosion allowance may be counted as compensation (*see* Fig. 3.17).

d) *Compensation of openings in flat end plates*

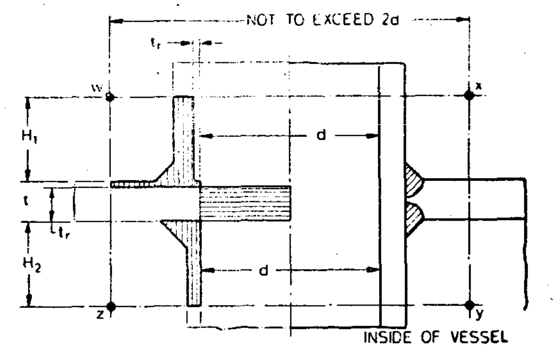
1) Flat plates that have an opening with a diameter that does not exceed one-half of the end plate diameter shall have a total cross-sectional area of compensation not less than that required by equation 3.32:

$$A = d.t_r \quad \ldots (3.32)$$

where

A, d and t_r are as defined above.

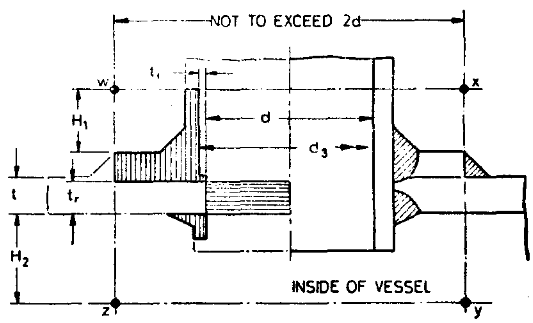
2) Flat plates having an opening with a diameter exceeding one-half of the end diameter shall be designed as a flange (*see* **3.10**).



AREA OF COMPENSATION ▥ TO BE NOT LESS THAN AREA ▤

Thickness exaggerated for clarity and weld profiles shown diagrammatically only.

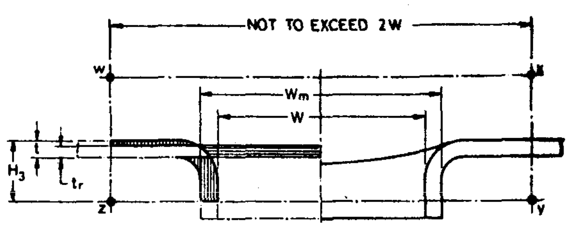
FIG. 3.15 SIMPLE 'THROUGH' BRANCH CONNECTION, SHOWING EFFECTIVE AREA FOR COMPENSATION



AREA OF COMPENSATION ▥ TO BE NOT LESS THAN AREA ▤

Thickness exaggerated for clarity and weld profiles shown diagrammatically only.

FIG. 3.16 COMPENSATED BRANCH CONNECTION, SHOWING EFFECTIVE AREA FOR COMPENSATION



AREA OF COMPENSATION ▥ TO BE NOT LESS THAN AREA ▤

Additional compensation provided, if necessary.

FIG. 3.17 FLANGED-IN OPENING, SHOWING EFFECTIVE COMPENSATION

3.8.5.3 *Compensation for openings subject to external pressure* — This need be only 50 percent of that required in **3.8.5.2** where t_r is the required minimum thickness under external pressure.

3.8.6 *Tell-Tale Holes* — Compensating rings and similar constructions which may have chambers sealed in by the welding construction shall have at least one tell-tale hole tapped to P ¼ size (*see* IS : 554-1964*).

3.8.7 *Screwed Connections*

3.8.7.1 *Screw threads* — Threads shall be in accordance with IS : 554-1964*, IS : 2643-1964†, IS : 3333 (Part I)-1967‡, and IS : 4218-1968§. The following constructions are permitted (*see* Fig. G.1 to G.5):

a) Threads may be tapered or parallel, but if parallel threads are used, a collar on the pipe and a facing around the hole shall be arranged to provide a joint-face; and

b) Screwed connections should not exceed P 1½ size (*see* IS : 554-1964*) or equivalent.

3.8.7.2 *Tapped holes in plates* — The maximum diameter shall not exceed the thickness of the plate before adding corrosion allowance.

3.8.7.3 *Welded sockets* — These may be used for construction as shown in Fig. G.3 to G.5.

3.8.8 *Studded Connections*

3.8.8.1 Whenever possible, it is recommended that studded connections be avoided. The vessel shall have a surface machined flat on a built up pad or on a properly attached plate for making the connection (*see* Fig. G.6 to G.12).

3.8.8.2 Where tapped holes are provided for studs, the threads shall be full and clean and shall engage the stud for a length not less than the larger of d_s or

$$0{\cdot}75d_s \times \frac{\text{allowable stress for the stud material at design temperature}}{\text{allowable stress for the tapped material at design temperature}}$$

where d_s is the stud diameter.

3.8.8.3 Stud holes should not penetrate to within 0·25 times the wall thickness from the inside vessel surface, after deducting corrosion allowance; but when stud holes penetrate to within 0·25 times the wall thickness from the inner surface of the vessel, additional metal shall be provided on the inside.

*Dimensions for pipe threads for gas list tubes and screwed fittings.

†Dimensions for pipe threads for fastening purposes.

‡Dimensions for petroleum industry pipe threads: Part I Line pipe threads.

§ISO metric screw threads.

3.8.9 *Branch Pipes*

3.8.9.1 The thickness of the branch pipe shall be adequate to meet the design requirement and shall in addition take into consideration the following factors:

a) Corrosion, erosion and wear;

b) Loads transmitted to the pipe from connecting piping; and

c) Accidental loadings that may happen during transit and erection.

But in no case it shall be less than that given by the following table:

Branch Nominal Size, mm	*Minimum Thickness**, mm*	
	Carbon & Ferritic Alloy Steels	Austenitic Stainless Steels
51 & smaller	5	3
65, 80, 90	6	5
100, 150	8	6
203, 254	10	8
305	11	10
356	13	10
406, 457	16	13

3.9 Access and Inspection Openings

3.9.0 *General*

3.9.0.1 All vessels subject to internal corrosion or having parts subject to erosion shall be provided with suitable inspection and/or access openings so located as to permit a complete visual examination of the interior of the vessels. In the case of vessels, in which vapours and/or fumes are likely to be present in such concentration as to be dangerous to persons entering the vessel for inspection and/or maintenance, manholes of adequate dimensions shall be provided†.

3.9.0.2 Manholes, where provided, shall be at least 450 mm in diameter if circular and if elliptical its dimensions shall not be less than 450 × 400 mm.

3.9.1 *Requirements for Inspection Openings and Manhole*

3.9.1.0 All vessels required by **3.9.0.1** to have inspection and/or access openings shall be provided with handholes, mudholes and manholes in number and sizes as follows; to facilitate cleaning and inspection:

Inside Vessel Diameter	*Requirement*
a) Up to 230 mm	Two openings each not less than 30 mm clear bore

*The thickness is in corroded condition.

†*See* Section 36, Chapter IV of the Indian Factories Act, 1948. *See also* IS : 3133-1965 'Manhole and inspection openings for chemical equipment'.

Inside Vessel Diameter	*Requirement*
b) 230 mm to 400 mm	Two openings each of not less than 45 mm clear bore
c) 400 mm to 600 mm	Two circular openings of minimum 90 mm diameter or two elliptical openings of minimum dimensions 90 × 70 mm
d) 600 mm to 900 mm	One manhole or two elliptical inspection openings of minimum dimensions 125 × 75 mm and if circular, of equivalent area.
e) 900 mm and above	At least one manhole except where the shape or use of vessel makes this impracticable in which case they shall be provided with sufficient elliptical handholes of minimum dimensions 150 × 100 mm, and if circular, of equivalent area.

NOTE — For any vessel for which manholes have to be provided to permit inspection or other purposes, the user should inform the manufacturer if dangerous fumes are liable to be present, after the vessel has been in operation, to such an extent as to involve the risk of persons being overcome thereby. In such a case, it is recommended that the vessel be provided with at least two manholes to facilitate rescue operations.

3.9.1.1 Openings for pipe connections, removable ends or cover plates may be used in place of inspection openings provided they are equal at least to the size of the openings permitted and can be conveniently removed for inspection. A single removable end or cover plate can be used in place of all other inspection openings if it is of such a size and location that a general view of the interior is given at least equal to that obtained with inspection openings otherwise required.

3.9.1.2 *Handling gear* — Lifting gear shall be provided to facilitate the handling of manhole covers which are in the vertical plane and which weigh more than 60 kg. A manhole cover located in the horizontal plane shall be fitted with lifting handles provided its weight does not exceed 100 kg. When the cover weight exceeds 100 kg, supporting gear shall be provided.

3.9.2 *Location*

3.9.2.1 Manholes shall be so located as to permit ready ingress and egress of a person.

3.9.2.2 Manholes or handholes in cylindrical shells shall, where practicable, be placed away from any welded seam.

3.9.2.3 Non-circular manhole or handhole openings shall, wherever possible, be arranged with their minor axes parallel to the longitudinal axis of the vessel.

3.9.3 *Minimum Gasket Bearing Width and Clearance for Manhole Cover Plates* — Manholes of the type in which the internal pressure forces the cover plate against a flat gasket shall have a minimum gasket bearing width of 17·5 mm. The total clearance between the manhole frame and the spigot or recess of such doors shall not exceed 3 mm, that is 1·5 mm all round.

3.9.4 *Threaded Openings* — When a threaded opening is to be used for inspection or cleaning purposes, the closing plug or cap shall be of a material suitable for the pressure and temperature conditions.

Threads may be tapered or parallel, but if parallel threads are used, a collar on the pipe and a facing around the hole shall be arranged to provide a joint face. Threads shall be in accordance with IS : 554-1964* or IS : 3333 (Part I)-1967†. Screwed connections should not exceed size P1½ of IS : 554-1964* or equivalent.

3.10 Bolted Flange Connections

3.10.1 *Types* — Bolted flanges may be divided into two broad types as follows:

a) *Wide-face flanges* in which the joint ring or gasket extends over the full width of the flange face. These are suitable only when used with comparatively soft gaskets. It is recommended that full-face joint flanges should not be used for pressures exceeding 20 kgf/cm² or temperatures exceeding 250°C.

b) *Narrow face joint flanges* in which the joint ring or gasket does not extend beyond the inside of the bolt holes (*see* **4.3**).

3.10.2 Flanges to IS : ....‡ or equivalent shall be used for connections to external piping. Flanges not covered by IS : ....‡ like shell flanges, which are not subject to appreciable loads due to external bending moments, shall conform to IS : 4864 to 4870-1968¶. Non-standard flanges not covered by these or other Indian Standard specifications may be designed in accordance with the requirements of **4**.

3.10.3 *Attachment of Flanges* — Bolted flanges may be attached to the vessel or branch pipe by any of the methods given in Fig. G.39 to G.44.

3.11 Ligament Efficiency

3.11.1 *General* — Where a shell is drilled with multiple holes, for example, in tube plates, its strength is reduced in proportion to the metal removed and according to the relative arrangement of the holes. In such cases it is necessary to calculate the strength of the ligaments between the holes. In the clauses that follow, methods for calculating the ligament efficiency are given. The shell thickness and the working pressure shall be based on the ligament having the lowest efficiency.

*Dimensions for pipe threads for gas list tubes and screwed fittings.

†Dimensions for petroleum industry pipe threads : Part I Line pipe threads.

‡Specification for steel pipe flanges (*under preparation*).

¶Dimensions for shell flanges for vessels and equipment.

3.11.2 *Drilling Parallel to the Axis* — When the tube holes are drilled in a cylindrical shell parallel to its axis, the efficiency J of ligaments shall be determined as follows.

3.11.2.1 *Regular drilling* — When the holes are regularly spaced along the line in question, the following equation shall apply:

$$J = \frac{p - d}{p} \quad \dots \quad (3.33)$$

where

p = pitch of tube holes, and

d = diameter of tube holes.

3.11.2.2 *Irregular drilling* — When the pitch of holes along the line in question is unequal, the following equation shall apply (Fig. 3.18):

$$J = \frac{p - n\,d}{p} \quad \dots \quad (3.34)$$

where

p = total length between centres corresponding to n consecutive ligaments. This length should conform to conditions specified in **3.11.5**;

n = number of tube holes in length p; and

d = diameter of tube holes.

3.11.3 *Circumferential Drilling* — When bending stresses due to weight are negligible, the efficiency of ligaments between holes in the case of a circumferential drilling shall not be used in the calculation of thickness of a cylindrical shell, provided that the efficiency of circumferential ligaments calculated according to **3.11.2.1** or **3.11.2.2** is at least one-half of the efficiency of longitudinal ligaments.

If this condition is not complied with, equation 3.1 shall be used with J equal to twice the efficiency of circumferential ligaments calculated according to **3.11.2.1** or **3.11.2.2**. For applying in **3.11.2.1** or **3.11.2.2** the pitch of tubes shall be measured either on the flat plate before rolling or along the median line after rolling.

3.11.4 *Drilling Along a Diagonal Line*

3.11.4.1 When bending stresses due to weight are negligible and the tube holes are arranged along a diagonal line with respect to the longitudinal axis, the efficiency J of corresponding ligaments is given in Fig. 3.19 with the ratio b/a on the abscissa and the ratio $\frac{2a - d}{2a}$, or $\frac{d}{a}$ used as a parameter where a and b are to be measured as shown in Fig. 3.20A and 3.20B, d is equal to diameter of the tube holes, and α is the angle of centre line of cylinder to centre line of diagonal holes.

NOTE — The dimension b shall be measured either on the flat plate before rolling or on the median line after rolling.

The data on Fig. 3.19 are based on the following formula:

$$J = \frac{2}{A + B + \sqrt{(A - B)^2 + 4C^2}}$$

where

$$A = \frac{\cos^2\alpha + 1}{2\left(1 - \frac{d\cos\alpha}{2a}\right)}$$

$$B = \tfrac{1}{2}\left(1 - \frac{d\cos\alpha}{a}\right)(\sin^2\alpha + 1)$$

$$C = \frac{\sin\alpha\cos\alpha}{2\left(1 - \frac{d\cos\alpha}{a}\right)}$$

$$\cos\alpha = \frac{1}{\sqrt{1 + \frac{b^2}{a^2}}}$$

$$\sin\alpha = \frac{1}{\sqrt{1 + \frac{a^2}{b^2}}}$$

3.11.4.2 The same rule shall apply for the case of drilling holes to a regular saw-tooth pattern as shown in Fig. 3.20C.

3.11.4.3 In the case of a regular staggered spacing of tube holes, the smallest value of the efficiency J of all the ligaments (longitudinal, circumferential, and diagonal), is given in Fig. 3.21 by the ratio p_c/p_L on the abscissa:

and the ratio $\frac{p_L - d}{p_L}$ or $\frac{d}{a}$

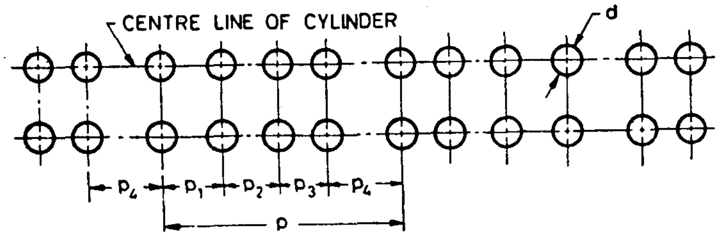


FIG. 3.18 IRREGULAR DRILLING

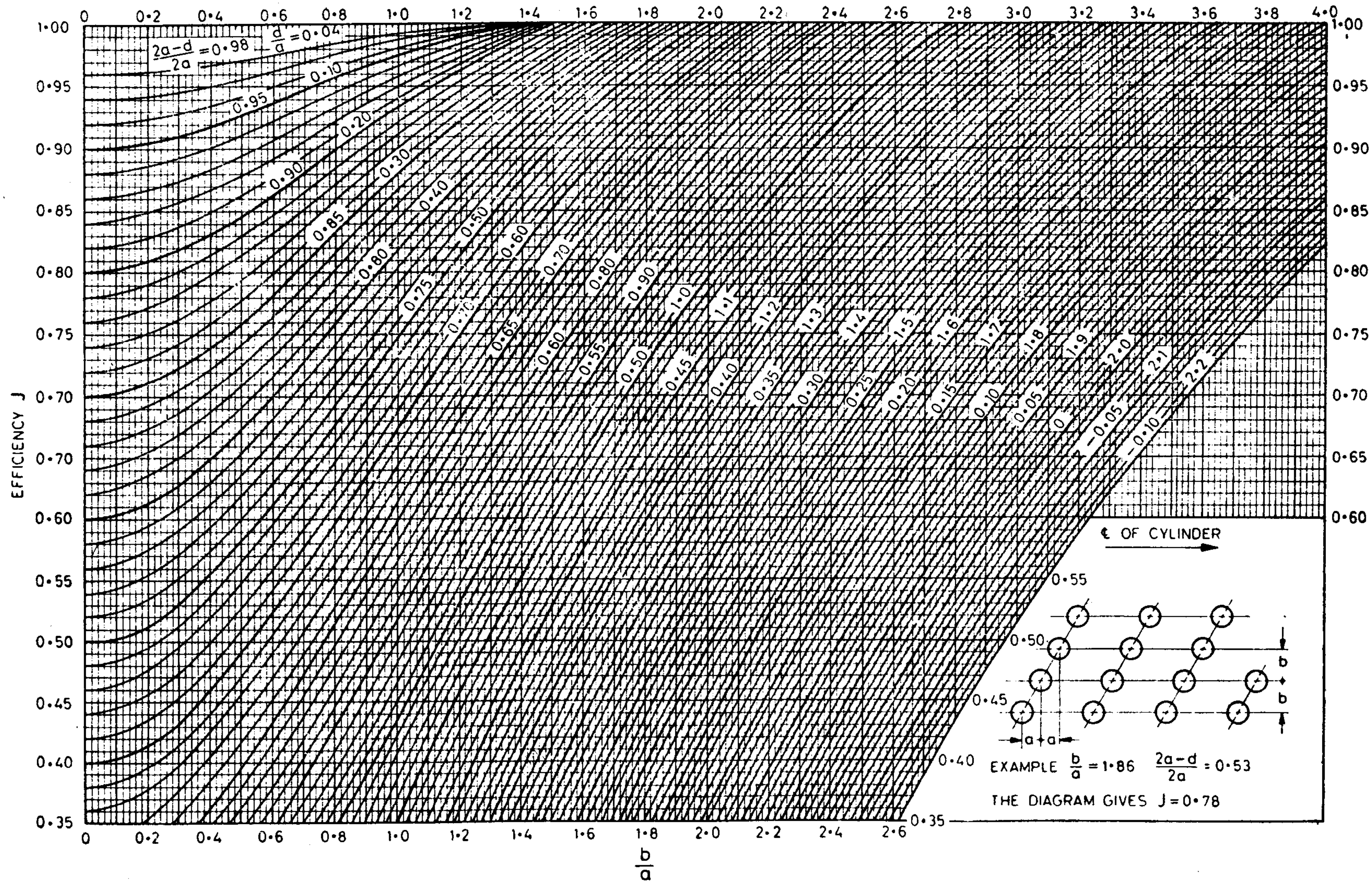


Fig. 3.19 Efficiency of Ligament Along a Diagonal Line

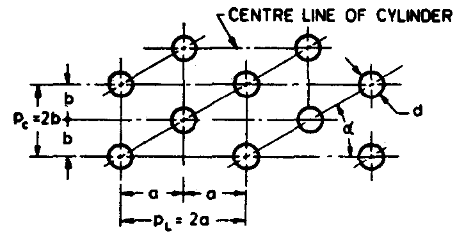


Fig. 3.20A Regular Staggering of Holes

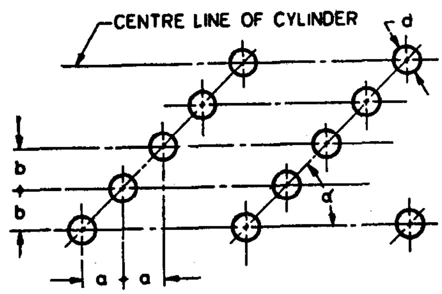


Fig. 3.20B Spacing of Holes on a Diagonal Line

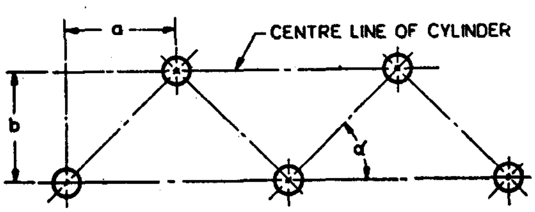


Fig. 3.20C Regular Saw Tooth Pattern of Holes

where

d = diameter of the tube holes,

p_c = $2b$ = twice the distance between circumferential rows of holes,

p_L = $2a$ = twice the distance between axial rows of holes, and

α = angle of centre line of cylinder to centre line of diagonal holes.

Note — The dimension p_c shall be measured either on the flat plate before rolling or on the median line after rolling. The data on Fig. 3.21 are based on the same formulae as Fig. 3.19.

3.11.5 *Length Which Can be Taken into Consideration for Drilling of Unequally Spaced Holes* — Where holes are unequally spaced, the average ligament efficiency J (used in the equation 3.1) shall be not more than what can be calculated [using the equation (3.34)] at any part over a length equal to the inside diameter of the shell (maximum 1 500 mm), or not more than 1·25 times that obtained over a length equal to the inside radius (maximum 750 mm) taken at the least favourable part.

A lower efficiency calculated over a shorter length need not be considered.

If the unequally spaced holes form a symmetrical pattern over a length greater than the inside diameter of the shell with a maximum of 1 500 mm to give a greater efficiency over such length than is obtained above, then this greater efficiency may be used.

When holes spaced longitudinally along a drum are not in a straight line, the equivalent longitudinal pitch for each spacing may be used in the application of the above rules. This equivalent pitch is obtained by multiplying the actual longitudinal pitch by the equivalent efficiency obtained from Fig. 3.19 for each spacing.

3.11.6 Tube plates in heat exchangers and pressure vessels shall be designed in accordance with the requirements of IS : 4503-1967*.

3.12 Jacketed Vessels

3.12.1 *General* — In addition to the requirements stated elsewhere in this code, the design of jacketed vessels shall take into consideration the following factors:

a) The inner vessel shall be designed to resist the full differential pressure that may exist under any operating conditions, including accidental vacuum in the inner vessel due to condensation of vapour contents.

b) The local stresses that may be caused by differential expansion between the jacket and the jacketed vessel.

c) Where the inner vessel is to operate under vacuum and the hydraulic test pressure for the jacket is correspondingly increased to test the inner vessel externally, care shall be taken that the jacket shell is designed to withstand this extra pressure.

3.12.2 *Attachment* — The jackets may be secured to the shell or ends or both by means of any suitable bolted or welded connections that is appropriate under the conditions of service (*see* Fig. G.45 to G.59 and G.66).

3.12.3 *Stays* — Stays may be used to secure the jacket to the jacketed vessel or end. Wherever they are provided, the surfaces shall be calculated as flat stayed surfaces (*see* **3.7**). Stays which require perforation of the walls of the inner vessel shall not be used.

3.12.4 *Outlets* — Outlets which pass through the jacket space or through recesses in jackets are common practice in the case of jacketed vessels (*see* Fig. G.60 to G.65).

3.12.5 *Compensation* — Where reinforcement is required it shall be in accordance with the requirements of **3.8**.

*Specification for shell and tube type heat exchangers.

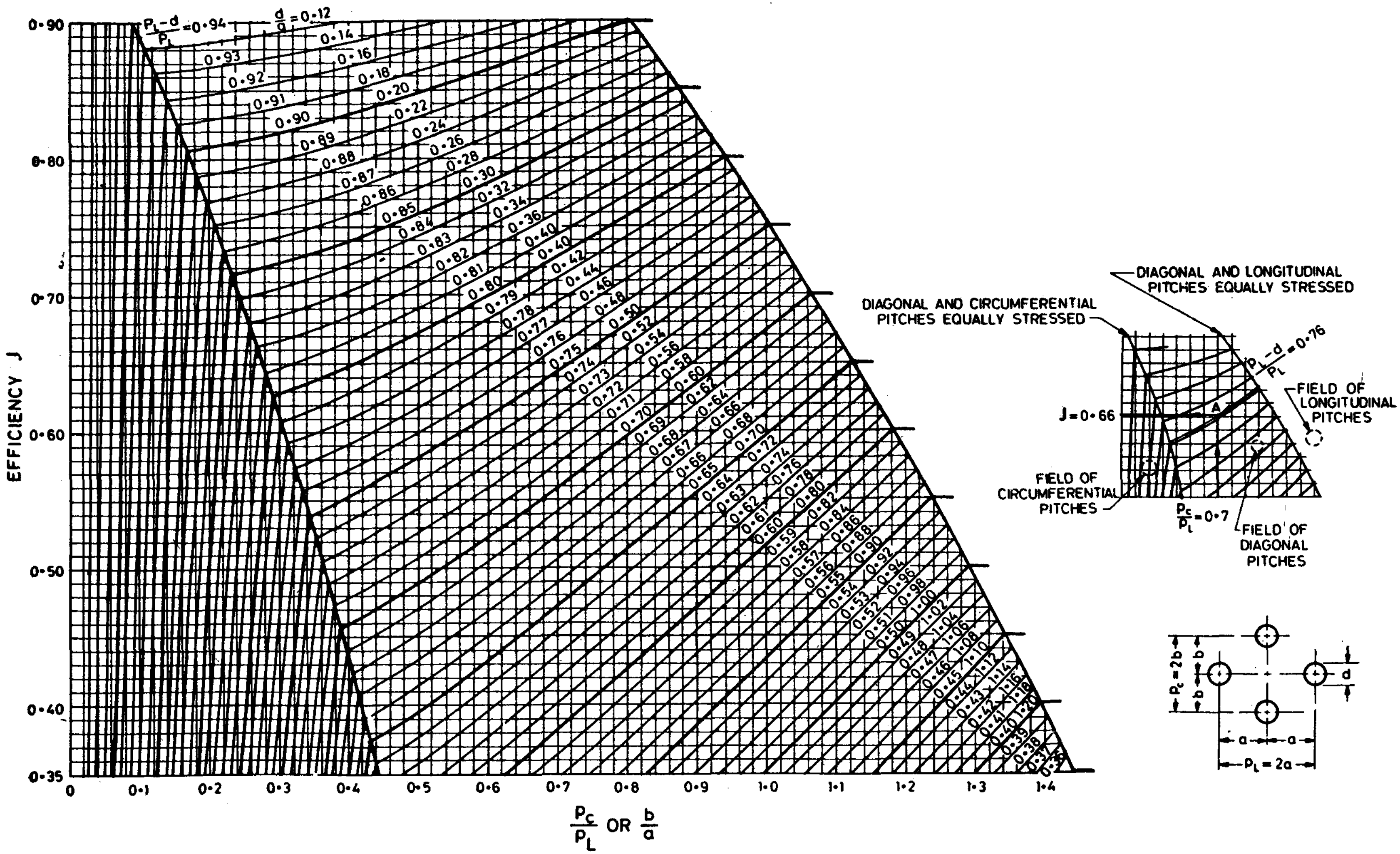


Fig. 3.21 Efficiency of Ligaments Between Holes

3.13 Supports — (*See also* Appendix C).

3.13.1 *General Design* — The details of supports and internal structures shall conform to good practice. Care shall be taken that the temperature gradients in external structures immediately adjacent to the shell do not produce stresses in excess of those laid down as permissible. If necessary, lagging should be applied to limit the temperature gradient to a value producing acceptable stresses. Loads arising from differential thermal expansion of the shell and the supporting structure in general shall not produce stresses in excess of those permitted by the respective specification. External stays or internal framing that may be used for supporting internal parts may be used to provide a stiffening effect on the shell where exterior supporting structures, which do not form part of the vessel, should comply with the requirements of IS : 800-1962*. When such supports are to be constructed in reinforced concrete they should comply with the requirements of IS : 456-1964†.

In case of load carrying attachments welded directly to pressure parts, the material and the deposited weld metal shall be compatible with that of the pressure part.

3.13.2 *Vertical Vessels*

3.13.2.1 *Bracket support* — Where vertical vessels are supported on lugs or brackets attached to the shell (Fig. 3.22A), the supporting members under the bearing attachments shall preferably be as close to the shell as clearance for insulation will permit. The choice between a number of brackets and a ring girder will depend upon the conditions for each individual vessel.

3.13.2.2 *Column support* — Vertical vessels supported on a number of posts or columns may require bracing or stiffening by means of a ring girder, internal partition or similar device in order to resist the force tending to buckle the vessel wall.

3.13.2.3 *Skirt support* — This type of support as indicated in Fig. 3.22B and 3.22C should be not less than 7 mm thick in corroded condition. Where the product of skirt diameter (mm), thickness (mm), and temperature at the top of the skirt above ambient (deg) exceeds 16×10^6 (mm² deg) account should be taken of the discontinuity stresses in both skirt and vessel induced by the temperature gradient in the upper section of the skirt. It is recommended that these stresses should be assessed by the criteria of **3.3.2.4** and Appendix C.

Where the value of the product is less than 16×10^6 (mm² deg) the nominal compressive stress in the skirt should not exceed one-half of the yield stress of the skirt material at the temperature concerned or the value expressed by:

$$f_{max} = \frac{0{\cdot}125\ E.t}{D} \cos \alpha \qquad \dots (3.35)$$

where

E = elastic modulus in kgf/mm² (*see* Tables 3.1 to 3.4),

t = skirt thickness in mm,

D = skirt diameter in mm, and

α = half the top angle of the conical skirt (for cylindrical skirts $\cos \alpha = 1$).

3.13.3 *Horizontal Vessels*

3.13.3.1 Horizontal vessels may be supported by means of saddles, equivalent leg supports or ring supports as shown in Fig. 3.22D and Fig. 3.22E.

The welds attaching ring supports to the vessel should have a minimum leg length equal to the thickness of the thinner of the two parts being joined together.

3.13.3.2 Saddles may be used for vessels of which the wall is not too thin. Saddles should preferably extend over at least 120 degrees of the circumference of the vessel. For thin vessels it may be desirable to place the saddles at points near the ends of the vessel.

3.13.3.3 For thin-walled vessel where excessive distortion due to the weight of the vessel may be expected, ring supports as shown in Fig. 3.22E, are recommended. Where practicable, two ring supports only are preferable.

3.14 Internal Structures

3.14.1 Internal structures and fittings shall be designed in accordance with good engineering practice and shall be arranged as far as practicable to avoid imposing local concentrated loads on the vessel.

3.14.2 Local loads from internal structures or from vessel contents shall be carried, where possible, by means of suitable stiffeners and or spacers directly to the vessel supports and thus to the foundations without stressing the vessel walls or ends.

3.14.3 Horizontal cylindrical vessels, which are provided with vertical external tower like extensions, should, where necessary, have the extensions supported independently of the vessel.

*Code of practice for use of structural steel in general building construction (*under revision*).

†Code of practice for plain and reinforced concrete for general building construction (*second revision*).

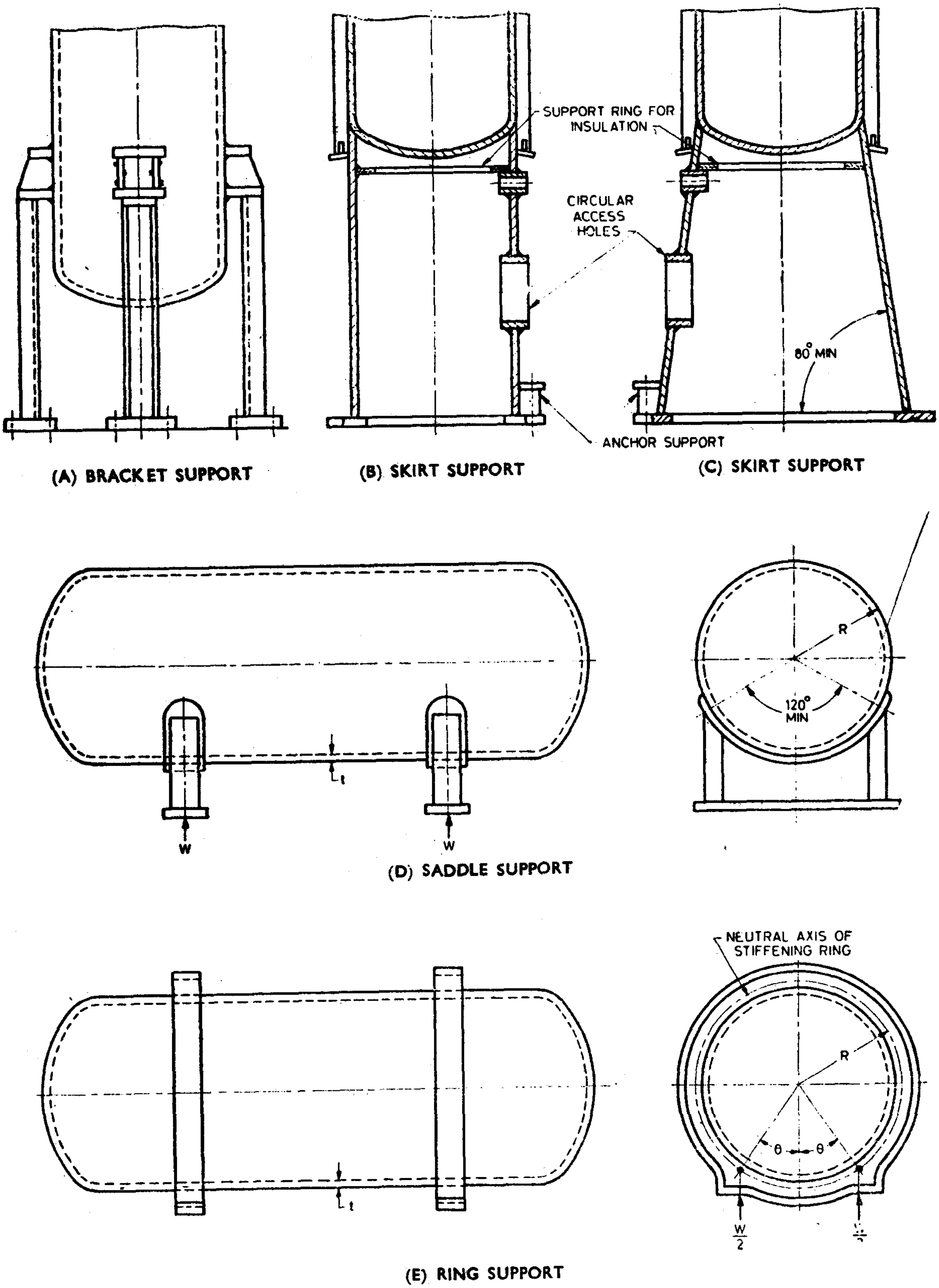


FIG. 3.22 SUPPORTS

4. FLANGE CALCULATIONS FOR NON-STANDARD FLANGES

4.1 General

4.1.1 The rules in this clause apply specifically to the design of bolted flanged connections and are to be used in conjunction with the applicable requirements of this standard.

These rules provide only for hydrostatic end loads and gasket seating. Where suitable, flanges complying with the appropriate Indian Standards (*see* **3.10.2**) shall be used and in such cases the calculations required by this section need not be carried out.

4.1.2 The design of a flange involves the selection of the gasket (material, type and dimensions), flange facing, bolting, hub proportions, flange width, flange thickness. Flange dimensions shall be such that the stresses in the flange, calculated in accordance with **4.7** do not exceed the values specified in **4.8**.

4.1.3 Hub flanges shall not be made by machining the hub directly from plate materials except subject to special approval by the purchaser.

4.1.4 The thickness of flanges shall be determined as the greater required either by the operating or by the bolting-up conditions and in all cases both conditions shall be calculated in accordance with the following:

a) *Operating conditions* — The operating conditions are the conditions required to resist the hydrostatic end force of the design pressure tending to part the joint, and to maintain on the gasket or joint-contact surface sufficient compression to assure a tight joint, all at the design temperature. The minimum load is a function of the design pressure, the gasket material, and the effective gasket or contact area to be kept tight under pressure (equation 4.1), and determines one of the two requirements for the amount of the bolting, A_{m1}. This load is also used for the design of the flange (equation 4.3).

b) *Bolting-up conditions* — The bolting-up conditions are the conditions existing when the gasket or joint-contact surface is seated by applying an initial load with the bolts when assembling the joint, at atmospheric temperature and pressure. The minimum initial load considered to be adequate for proper seating is a function of the gasket material, and the effective gasket or contact area to be seated (equation 4.1) and determines the other of the two requirements for the amount of bolting, A_{m2}. For the design of the flange, this load is modified (equation 4.4), to take account of the operating conditions, when these govern the amount of bolting required, A_m as well as the amount of bolting actually provided, A_b.

4.1.5 The following rules are based upon considerations of strength. In unusual circumstances consideration may be required to ensure freedom from leakage*.

4.2 Fasteners — It is recommended that bolts and studs have a nominal diameter of not less than 12 mm. If bolts or studs smaller than 12 mm are used, bolting material shall be of alloy steel. Precautions shall be taken to avoid over stressing smaller diameter bolts. Bolts and studs shall not have a thread of coarser pitch than 3 mm pitch except by special approval by the purchaser.

4.3 Classification of Flanges — For design purposes, flanged facings shall come under one of the following categories:

a) *Narrow-Faced Flanges* — These are flanges where all the face contact area lies inside the circle enclosed by the bolt holes. They may be of the gasketed type or have face-to-face joints or a combination of both with or without a seal weld. The design rules for such flanges are given below.

b) *Wide-Faced Flanges* — These are flanges with face contact area outside the circle enclosed by the bolt holes. The design rules for these flanges are not included (*see* **4.1**).

4.4 Flanges Subject to Internal Pressure (Narrow-Faced Flanges) — The flange design methods outlined in this clause, together with **4.5**, **4.6**, **4.7** and **4.8** are applicable to circular flanges under internal pressure.

The notation described below is used in the formulae for the design of flanges (*see also* Fig. 4.1).

A = outside diameter of flange or, where slotted holes extend to the outside of the flange, the diameter to the bottom of the slots, mm².

A_b = actual total cross-sectional area of bolts at root of thread or section of least diameter under stress, mm².

A_m = total required cross-sectional area of bolts, taken as the greater of A_{m1} and A_{m2}, mm².

A_{m1} = total cross-sectional area of bolts at root of thread or section of least diameter under stress, required for the operating conditions, mm² = W_{m1}/S_b.

A_{m2} = total cross-sectional area of bolts at root of thread or section of least diameter under stress, required for gasket seating, mm² = W_{m2}/S_a.

B = inside diameter of flange, mm.

C_F = bolt pitch correction factor

$$\sqrt{\frac{\text{bolt spacing}}{2\,(\text{bolt diameter}) + t}}$$

*Reference. Murray N.W. and Stuart D.G. 'Behaviour in large taper hub flanges'. Symposium on pressure vessel research towards better design. Inst. Mech. E. 1961.

b = effective gasket or joint-contact-surface seating width, mm (*see* Note in **4.5.2**).

$2b$ = effective gasket or joint-contact-surface pressure width, mm (*see* **4.5**).

b_0 = basic gasket seating width, mm (from Table 4.2 and Fig. 4.2).

C = bolt-circle diameter, mm

d = factor, for integral-type flanges

$$d = \frac{U}{V} h_0 g_0^2$$

for loose-type flanges

$$d = \frac{U}{V_L} h_0 g_0^2$$

e = factor, for integral-type flanges

$$e = \frac{F}{h_0}$$

for loose-type flanges

$$e = \frac{F_L}{h_0}$$

F = factor for integral-type flanges (from Fig. 4.4).

F_L = factor for loose-type flanges (from Fig. 4.6).

= hub stress-correction factor for integral flanges from Fig. 4.8 (when greater than 1 this is the ratio of the stress in the small end of hub to the stress in the large end); (for values below limit of figure use $f = 1$).

G = diameter at location of gasket load reaction. Except as noted in sketch A of Fig. 4.1, G is defined as follows (*see* Fig. 4.2).

when $b_0 \leqslant 6{\cdot}3$ mm, G = mean diameter of gasket contact face, mm:

when $b > 6{\cdot}3$ mm, G = outside diameter of gasket contact face less $2b$, mm.

g_0 = thickness of hub at small end, mm.

g_1 = thickness of hub at back of flange, mm.

H = total hydrostatic end force, kgf = $\frac{\pi}{400} G^2 p$.

H_D = hydrostatic end force on area inside of flange kgf = $\pi/400\ B^2 p$.

H_G = gasket load (difference between flange design bolt load and total hydrostatic end force), kgf $H_G = W_{m_1} - H = H_p$ for operating condition, $H_G = W$ for gasket seating condition.

H_p = total joint-contact-surface compression load, kgf = $\frac{2\pi b G m p}{100}$

H_T = difference between total hydrostatic end force and the hydrostatic end force on area inside of flange, kgf = $H - H_D$.

h = hub length, mm.

h_D = radial distance from the bolt circle, to the circle on which H_D acts, as prescribed in **4.6**, mm.

h_G = radial distance from gasket load reaction to the bolt circle, mm

$$= \frac{C - G}{2}.$$

$h_0 = \sqrt{B g_0}$, mm

h_T = radial distance from the bolt circle to the circle on which H_T acts as prescribed in **4.6**, mm.

K = ratio of outside diameter of flange to inside diameter of flange = A/B.

$$\lambda = \text{factor} = \left[\frac{te + 1}{T} + \frac{t^3}{d} \right]$$

M_0 = The greater of M_{op} or $\frac{M_{atm} \times S_{FO}}{S_{FA}}$

M_{atm} = total moment acting upon the flange for gasket seating conditions, kgf·mm.

M_{op} = total moment acting on the flange for operating conditions, kgf·mm.

m = gasket factor, obtained from Table 4.1 (*see* Note in **5.4.2**).

N = width, mm, used to determine the basic gasket seating width b_0, based upon the possible contact width of the gasket (*see* Table 4.2).

p = design pressure, kgf/cm². For flanges subject to external pressure, *see* **4.9**.

R = radial distance from bolt circle to point of connection of hub and back of flange, mm (integral and hub flanges),

$$\frac{C - B}{2} - g_1.$$

S_a = nominal bolt stress at ambient temperature, kgf/mm² (*see* Table 4.5).

S_b = nominal bolt stress at design temperature, kgf/mm² (*see* Table 4.5).

S_{FA} = nominal design stress for flange material at ambient temperature (gasket seating conditions), kgf/mm² from Table 2 1*.

S_{FO} = nominal design stresses for flange material at design temperature (operating condition), kgf/mm² from Table 2.1*.

S_H = calculated longitudinal stress in hub, kgf/mm².

S_R = calculated radial stress in flange, kgf/mm².

S_T = calculated tangential stress in flange, kgf/mm².

T = factor involving K (from Fig. 4.3).

t = flange thickness, mm

*The above definitions are based on the assumption that the materials for the flange ring and neck are not significantly different in their appropriate mechanical properties. If they are different, either the lower values should be used or special consideration given to the design.

U = factor involving K (from Fig. 4.3).

V = factor for integral-type flanges (from Fig. 4.5).

V_L = factor for loose-type flanges (from Fig. 4.7)

W = flange design bolt load, for the operating conditions or gasket seating, as may apply, kgf (*see* **4.5.3** and **4.9**).

W_{m1} = minimum required bolt load for the operating conditions, kgf (*see* **4.5**).

W_{m2} = minimum required bolt load for gasket seating, kgf (*see* **4.5**).

w = width, in mm, used to determine the basic gasket seating width b_0, based upon the contact width between the flange facing and the gasket (*see* Table 4.2).

Y = factor involving K (from Fig. 4.3).

y = gasket or joint-contact-surface unit seating load, kgf/mm² (*see* **4.5**).

Z = factor involving K (from Fig. 4.3).

4.4.1 *Loose-Type Flanges* — This type covers those designs where the method of attachment is not considered to give the mechanical strength equivalent of integral attachment, *see* Fig. 4.1 A, B, C and D for typical-loose-type flanges and the location of the loads and moments. Welds and other details of construction shall satisfy the dimensional requirements given in Fig. 4.1 B, C and D.

4.4.2 *Integral-Type Flanges* — This type covers designs of such a nature that the flange and nozzle neck, vessel, or pipe wall is considered to be the equivalent of an integral structure. In welded construction, the nozzle neck, vessel, or pipe wall is considered to act as a hub. *See* Fig. 4.1 E, F, F1, F2 and G for typical integral-type flanges and the location of the loads and moments. Welds and other details of construction shall satisfy the dimensional requirements given in Fig. 4.1 E, F, F1, F2 and G.

4.4.3 *Optional-Type Flanges* — This type covers designs where the attachment of the flange to the nozzle neck, vessel, or pipe wall is such that the assembly is considered to act as a unit, which shall be calculated as an integral flange, except that for simplicity the designer may calculate the construction as a loose-type flange provided none of the following values is exceeded:

$g_0 = 16$ mm, $\frac{B}{g_0} = 300$, $p = 21$ kgf/cm², operating temperature = 365°C.

(*see* Fig. 4.1 H, H1, H2 and J) for typical optional-type flanges. Welds and other details of construction shall satisfy the dimensional requirements given in Fig. 4.1 H, H1, H2 and J.

4.5 Bolt Loads

4.5.1 The minimum cross section of the bolting provided shall be adequate:

a) to prevent leakage under the operating conditions, and

b) to seat the gasket under the bolting-up condition.

4.5.1.1 *Operating condition* — To retain a leak-tight joint under pressure the minimum bolting required W_{m1} shall be given by equation 4.1:

$$W_{m1} = H + H_p \qquad \ldots \quad (4.1)$$

where $H = \pi/400\ G^2p$ for gasket flanges

$$H_p = \frac{2\pi\, bGmp}{100}$$

4.5.1.2 *Bolting-up condition* — For gasket seating the minimum bolt load required W_{m2} shall be:

$$W_{m2} = \pi\, bGy \qquad \ldots \quad (4.2)$$

4.5.2 The minimum required bolt area shall be adequate to provide the greater of the bolt loads determined by equations 4.1 and 4.2 above. This area shall be calculated by using bolt stresses at the temperatures appropriate to the two conditions:

that is, A_m is the greater of A_{m1} or A_{m2} ... (4.3)

where $A_{m1} = W_{m1}/S_b$

and $A_{m2} = W_{m2}/S_a$

The actual bolt area provided (A_b) shall be not less than A_m, and, to prevent damage to the gasket during bolting-up, shall not exceed the value given by:

$$A_b = \frac{2\pi yGN}{S_a} \qquad \ldots \quad (4.4)$$

If it is not practicable to adjust the actual bolt area to meet the latter requirement the whole procedure shall be repeated with a suitably modified gasket.

NOTE — *See* Table 4.1, Table 4.2 and Fig. 4.2 for suggested values of m, b and y.

The method used to tighten the bolts shall ensure that the design bolt stresses are attained.

4.5.3 Design bolt load W (flanges and bolted ends)

Loads used in the design of the flange shall be:

For operating condition, $W = W_{m1}$

For bolting-up condition, $W = \frac{A_m + A_b}{2} \times S_a$

NOTE — For flanges subject to external pressure *see* **4.9**.

LOOSE-TYPE FLANGES

Loading and dimensions not shown are same as shown in Sketch (B)

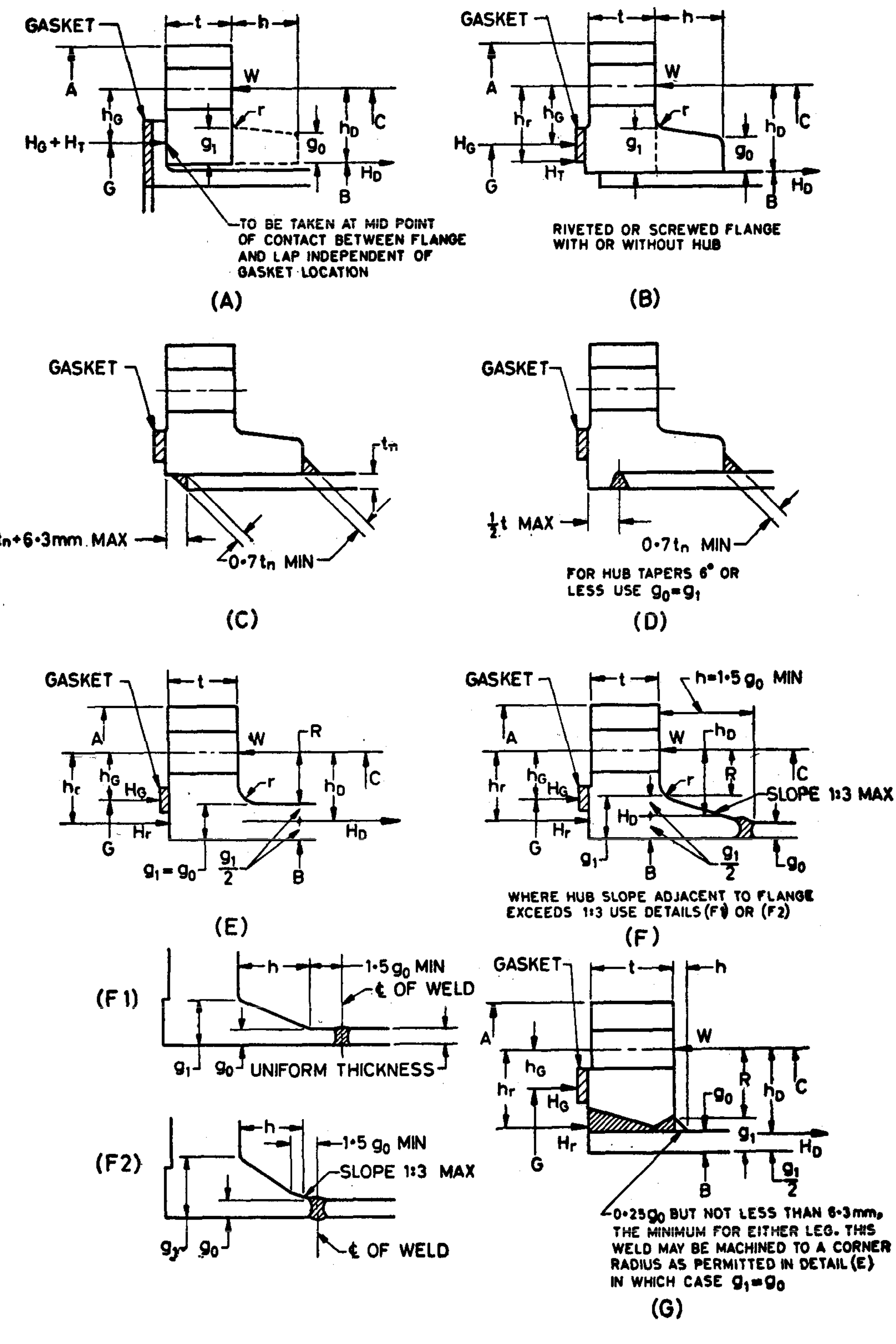
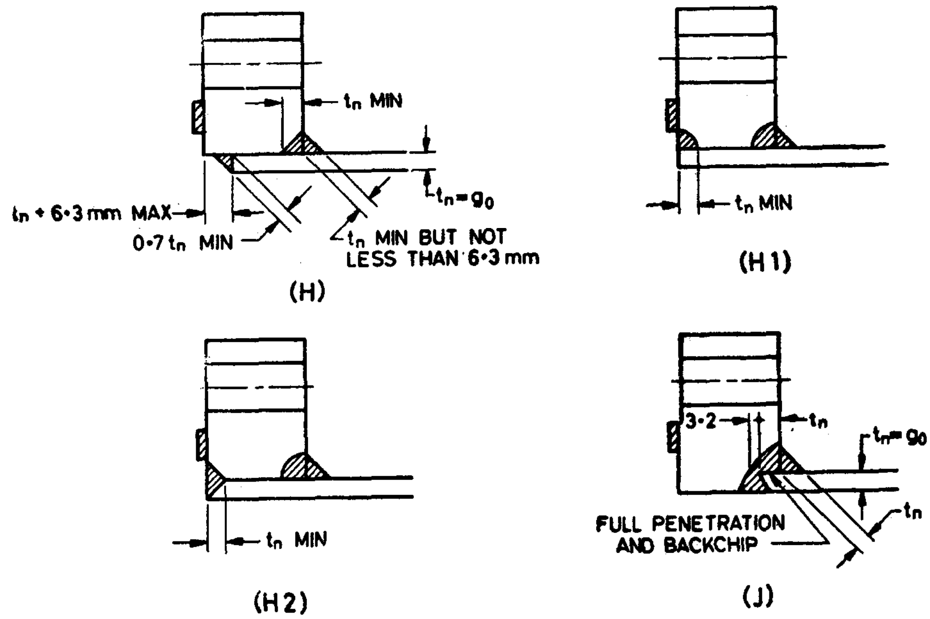


FIG. 4.1 CLASSIFICATION OF FLANGES FOR CALCULATION PURPOSES

(*Continued*)

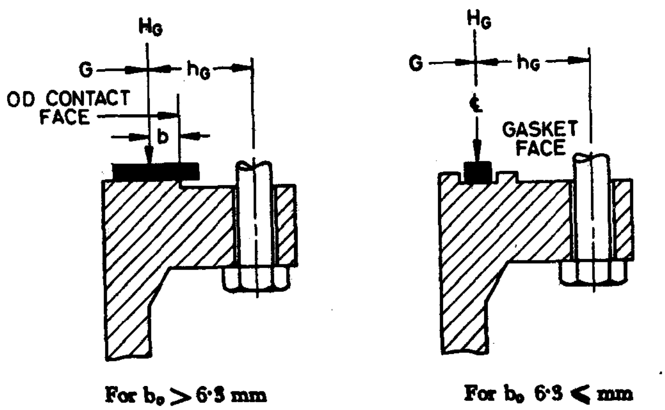
OPTIONAL-TYPE FLANGES

These may be calculated as either loose- or integral-type (*see* **4.4.1** and **4.4.2**). Loading and dimensions not shown are the same as (B) for loose-type flanges or (G) for integral-type



NOTE — Fillet radius r to be at least $0 \cdot 25\, g_1$, but not less than (4·5 mm). Raised, tongue-groove, male and female, and ring joint facings shall be in excess of the required minimum flange thickness t.

FIG. 4.1 CLASSIFICATION OF FLANGES FOR CALCULATION PURPOSES



Effective gasket seating width $b = b_o$, when $b_o = 6 \cdot 3$ mm
and $= 2 \cdot 5\sqrt{b_o}$, when $b_o > 6 \cdot 3$ mm

NOTE — The gasket factors listed only apply to flanged joints in which the gasket is contained entirely within the inner edges of the bolt holes.

FIG. 4.2 LOCATION OF GASKET LOAD REACTION

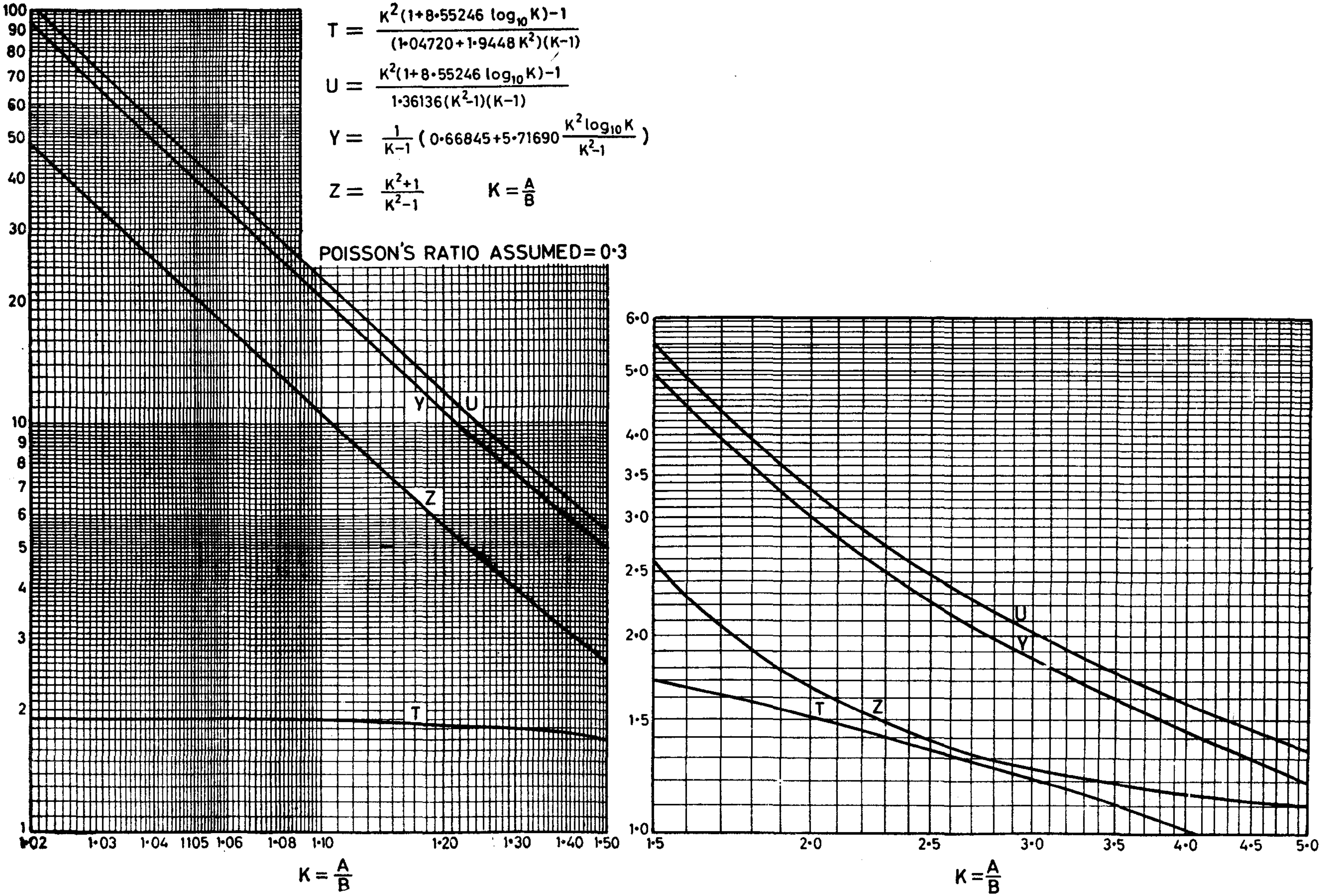


Fig. 4.3 Values of T, U, Y and Z for $K = \frac{A}{B}$ Greater Than 1·5

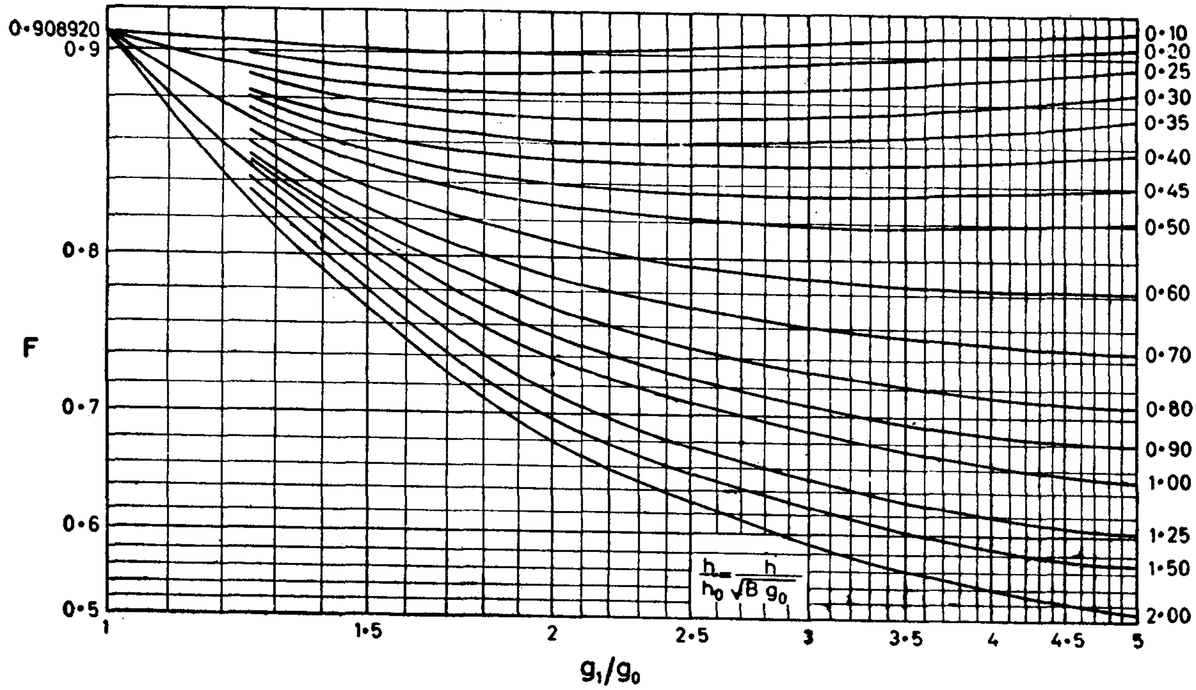


Fig. 4.4 Values of F (Integral Flange Factors)

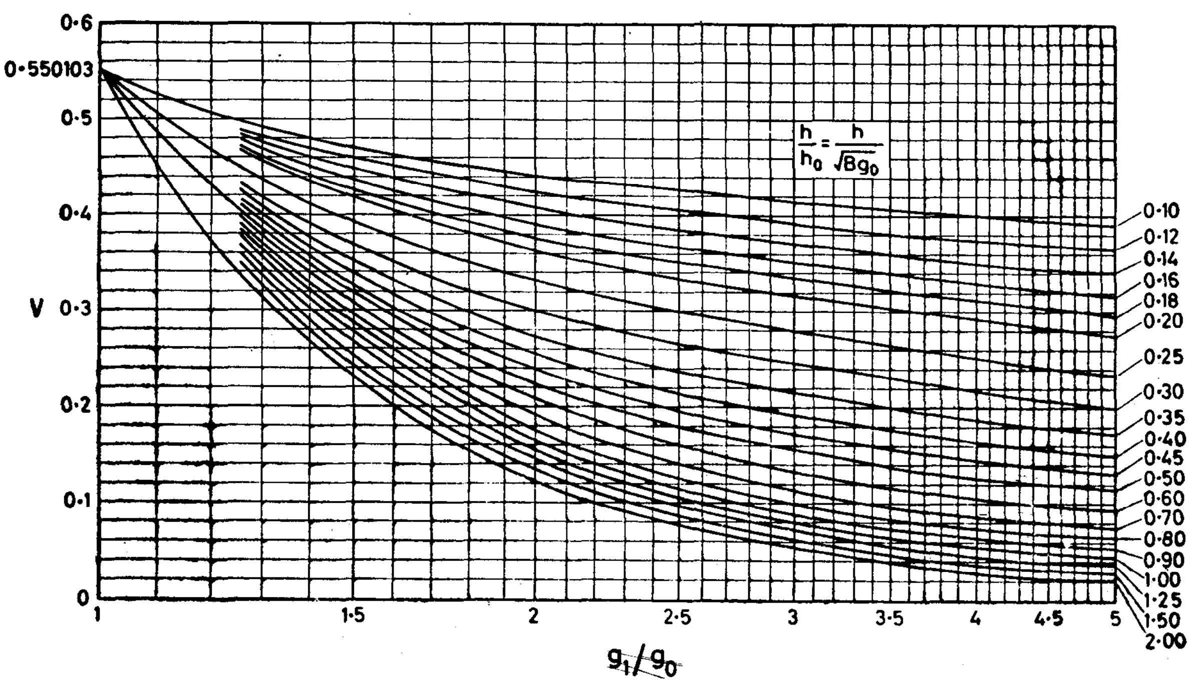


Fig. 4.5 Values of V (Integral Flange Factors)

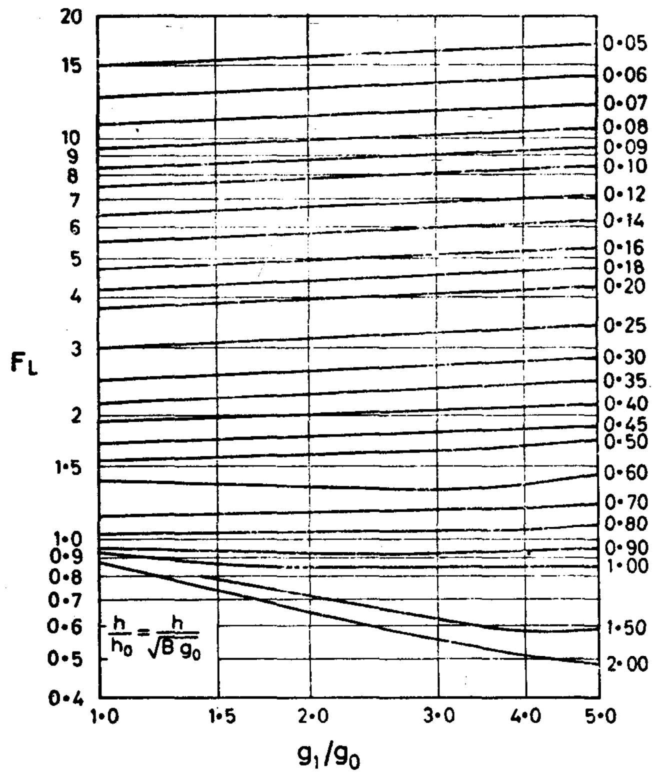


FIG. 4.6 VALUES OF F_L (LOOSE HUB FLANGE FACTORS)

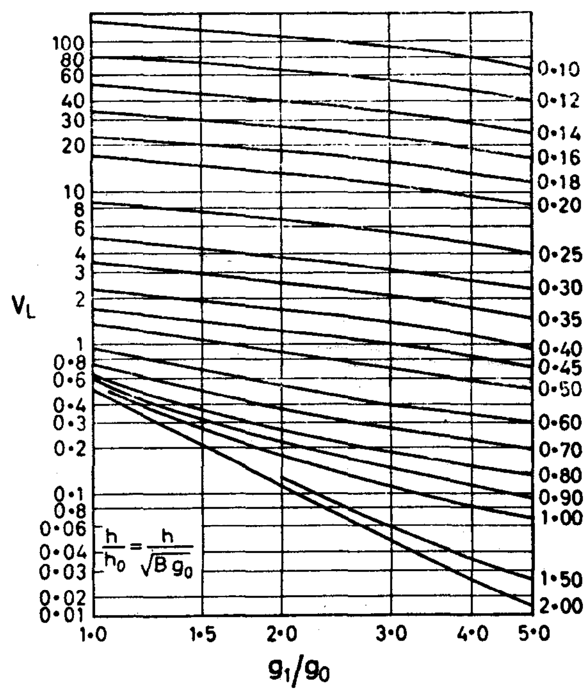


FIG. 4.7 VALUES OF V_L (LOOSE HUB FLANGE FACTORS)

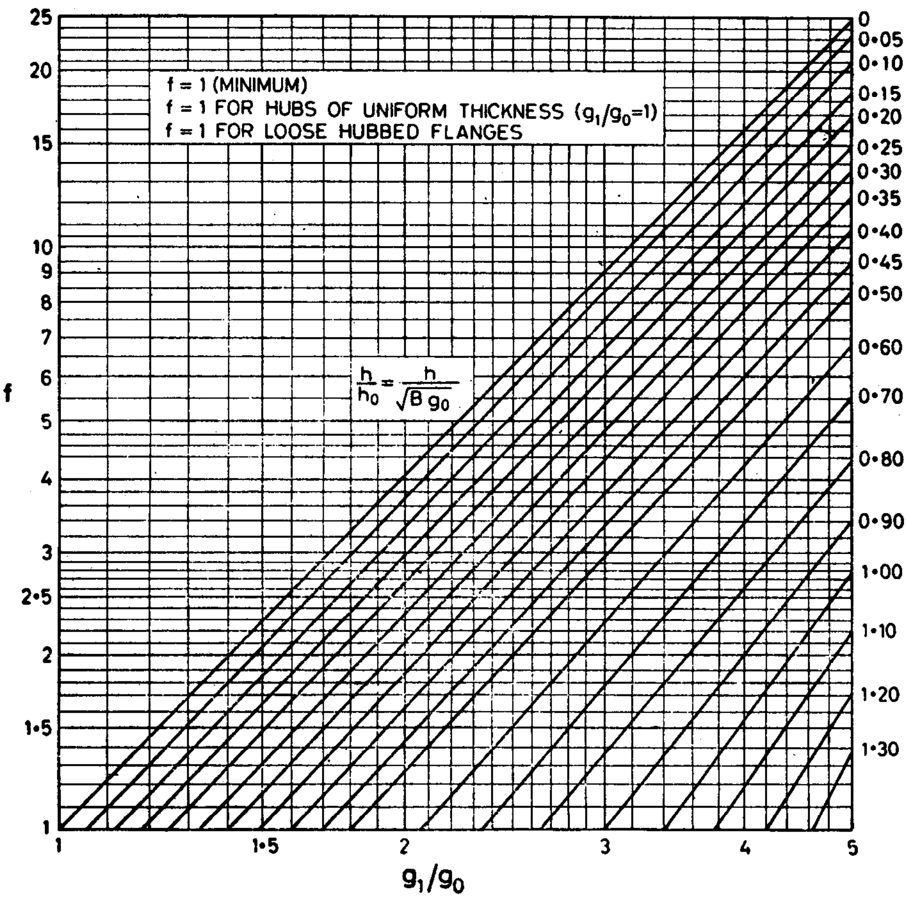


FIG. 4.8 VALUES OF f (HUB STRESS CORRECTION FACTOR)

TABLE 4.1 GASKET MATERIALS AND CONTACT FACINGS

[Gasket factors (m) for operating conditions and minimum design seating stress (y)]

NOTE — This table gives a list of many commonly used gasket materials and contact facings with suggested design values of m and y that have generally proved satisfactory in actual service when using effective gasket seating width b given in Table 4.2 and Fig. 4.2. The design values and other details given in this table are suggested only and are not mandatory.

DIMENSION N mm (*Min*)	GASKET MATERIAL	GASKET FACTOR m	MINIMUM DESIGN SEATING STRESS, y kgf/mm²	SKETCHES AND NOTES	REFER TO TABLE 4.2	
					Use Facing Sketch	Use Column
10	Rubber without fabric or a high percentage of asbestos fibre: Below 70 IRHD* 70 IRHD* or higher	 0·50 1·00	 0 0·14		1 (a, b, c, d), 4, 5	II
	Asbestos with a suitable binder for the operating conditions: 3·2 mm thick 1·6 mm thick 0·8 mm thick	2·00 2·75 3·50	1·12 2·60 4·57			

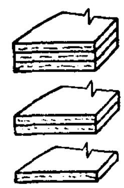
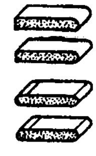
*See IS : 3400 (Part II)-1965 Methods of test for vulcanized rubbers: Part II Hardness; and IS : 638-1965 Sheet rubber jointing and rubber insertion jointing.

(*Continued*)

TABLE 4.1 GASKET MATERIALS AND CONTACT FACINGS — *Contd*

[Gasket factors (m) for operating conditions and minimum design seating stress (y)]

NOTE — This table gives a list of many commonly used gasket materials and contact facings with suggested design values of m and y that have generally proved satisfactory in actual service when using effective gasket seating width b given in Table 4.2 and Fig. 4.2. The design values and other details given in this table are suggested only and are not mandatory.

DIMENSION N (*Min*) mm	GASKET MATERIAL		GASKET FACTOR m	MINIMUM DESIGN SEATING STRESS, y kgf/mm²	SKETCHES AND NOTES	REFER TO TABLE 4.2	
						Use Facing Sketch	Use Column
10	Rubber with cotton fabric insertion		1·25	0·28		1 (a, b, c, d), 4, 5	II
	Rubber with asbestos fabric insertion, with or without wire reinforcement	3-ply	2·25	1·55			
		2-ply	2·50	2·04			
		1-ply	2·75	2·60			
	Vegetable fibre		1·75	0·77			
	Spiral-wound metal, asbestos filled	Carbon steel	2·50	2·04		1 (a, b)	
		Stainless steel or monel metal	3·00	3·16			
	Corrugated metal, asbestos inserted or Corrugated metal, jacketed asbestos filled	Soft aluminium	2·50	2·04			
		Soft copper or brass	2·75	2·60			
		Iron or soft steel	3·00	3·16			
		Monel metal or 4-6 percent chrome steel	3·25	3·87			
		Stainless steels	3·50	4·57			
	Corrugated metal	Soft aluminium	2·75	2·60		1 (a, b, c, d)	
		Soft copper or brass	3·00	3·16			
		Iron or soft steel	3·25	3·87			
		Monel metal or 4-6 percent chrome steel	3·50	4·57			
		Stainless steel	3·75	5·34			
	Flat metal jacketed asbestos filled	Soft aluminium	3·25	3·87		1a, 1b, 1c*, 1d*, 2*	
		Soft copper or brass	3·50	4·57			
		Iron or soft steel	3·75	5·34			
		Monel metal or 4-6 percent chrome steel	3·50	5·62			
		Stainless steels	3·75	6·33			

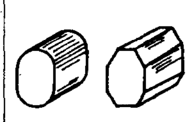
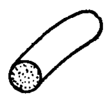
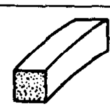
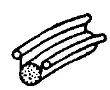
*The surface of a gasket having a lap should not be against the nubbin.

(*Continued*)

TABLE 4.1 GASKET MATERIALS AND CONTACT FACINGS — *Contd*

[Gasket factors (m) for operating conditions and minimum design seating stress (y)]

NOTE — This table gives a list of many commonly used gasket materials and contact facings with suggested design values of m and y that have generally proved satisfactory in actual service when using effective gasket seating with b given in Table 4.2 and Fig. 4.2. The design values and other details given in this table are suggested only and are not mandatory.

DIMENSION N (*Min*) mm	GASKET MATERIAL		GASKET FACTOR m	MINIMUM DESIGN SEATING STRESS, y kgf/mm²	SKETCHES AND NOTES	REFER TO TABLE 4.2	
						Use Facing Sketch	Use Column
10	Grooved metal	Soft aluminium Soft copper or brass Iron or soft steel Monel metal or 4-6 percent chrome steel Stainless steels	3·25 3·50 3·75 3·75 4·25	3·87 4·57 5·34 6·33 7·10		1 (a, b, c, d), 2, 3	II
6	Solid flat metal	Soft aluminium Soft copper or brass Iron or soft steel Monel metal or 4-6 percent chrome steel Stainless steels	4·00 4·75 5·50 6·00 6·50	6·19 9·14 12·66 15·33 18·28		1 (a, b, c, d), 2, 3, 4, 5	I
	Ring joint	Iron or soft steel Monel metal or 4-6 percent chrome steel Stainless steels	5·50 6·00 6·50	12·66 15·33 18·28		6	
—	Rubber O-rings : Below 75 IRHD* Between 75 and 85 IRHD*		 3† 6†	 0·07 0·15		7 only	
	Rubber square section rings : Below 75* IRHD Between 75* and 85* IRHD		 4† 9†	 0·10 0·28		8 only	II
	Rubber T-section rings : Below 75* IRHD Between 75* and 85* IRHD		 4† 9†	 0·10 0·23		9 only	

*See IS : 3400 (Part II) - 1965 Methods of test for vulcanized rubber : Part II Hardness; and IS : 638-1965 Sheet rubber jointing and rubber insertion jointing.

†These values have been calculated.

4.6 Flange Moments — Flange moments shall be calculated for both the operating condition and the bolting-up condition.

4.6.1 *Operating Condition* — The total flange moment is given by equation 4.5,

$$M_{op} = H_D h_D + H_T h_T + H_G h_G \quad \dots (4.5)$$

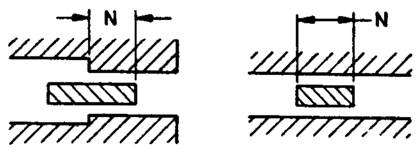
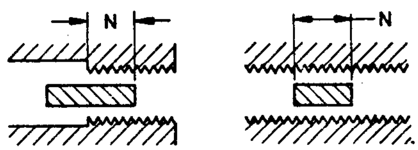
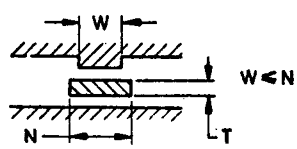
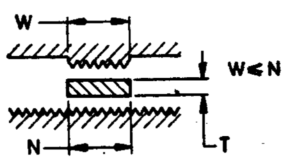
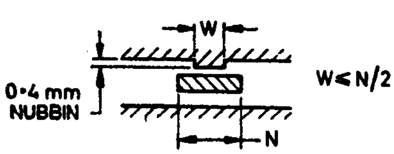
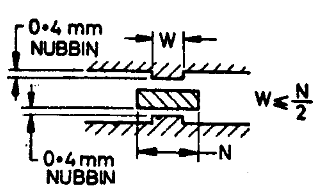
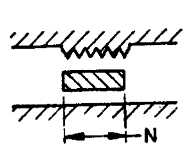
where $H_D = \dfrac{\pi B^2 p}{400}$

$$H_T = H - H_D$$

$$H_G = H_p$$

and h_D, h_T and h_G are obtained from Table 4.3.

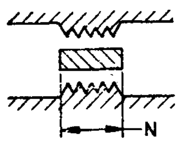
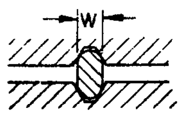
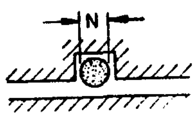
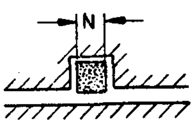
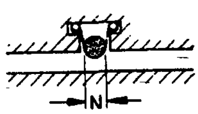
TABLE 4.2 EFFECTIVE GASKET WIDTH

	FACING SKETCH (EXAGGERATED)	BASIC GASKET SEATING WIDTH b_0	
		Column I	Column II
1a		$\frac{N}{2}$	$\frac{N}{2}$
1b*			
1c		$\frac{w+25T}{2}$; $\left(\frac{w+N}{4}\ Max\right)$	$\frac{w+25T}{2}$; $\left(\frac{w+N}{4}\ Max\right)$
1d*			
2		$\frac{w+N}{4}$	$\frac{w+3N}{8}$
3		$\frac{w}{2}$; $\left(\frac{N}{4}\ Min\right)$	$\frac{w+N}{4}$; $\left(\frac{3N}{8}\ Min\right)$
4*		$\frac{3N}{8}$	$\frac{7N}{16}$

*Where serrations do not exceed 0·4 mm depth and 0·8 mm width spacing, sketches 1b and 1d shall be used.

(*Continued*)

TABLE 4.2 EFFECTIVE GASKET WIDTH — *Contd*

	Facing Sketch (Exaggerated)	Basic Gasket Seating Width b_0	
		Column I	Column II
5*		$\frac{N}{4}$	$\frac{3N}{8}$
6		$\frac{w}{8}$	—
7		—	$\frac{N}{2}$
8		—	$\frac{N}{2}$
9		—	$\frac{N}{2}$

*Where serrations do not exceed 0·4 mm depth and 0·8 mm width spacing, sketches 1b and 1d shall be used.

TABLE 4.3 MOMENT ARMS FOR FLANGE LOADS UNDER OPERATING CONDITIONS

Type of Flange	h_D	h_T	h_G
Integral type flanges (*see* Fig. 4.1E, F, F1, F2, G, H, H1, H2 and J)	$R + 0{\cdot}5\,g_1$	$\frac{R + g_1 + h_G}{2}$	$\frac{C - G}{2}$
Loose type except lap joint flanges (*see* Fig. 4.1B, C, D and optional type flanges (*see* Fig. 4.1H, H1, H2 and J)	$\frac{C - B}{2}$	$\frac{h_D + h_G}{2}$	$\frac{C - G}{2}$
Lap joint flanges (*see* Fig. 4.1A)	$\frac{C - B}{2}$	$\frac{C - G}{2}$	$\frac{C - G}{2}$

4.6.2 *Bolting-Up Condition* — The total flange moment is given by equation 4.6:

$$M_{atm} = Wh_G \qquad \ldots (4.6)$$

where $W = \dfrac{(A_m + A_b)}{2} S_a$, (*see* **4.5.3**)

and $h_G = \dfrac{C - G}{2}$

4.7 Flange Stresses — Flange stresses shall be determined for the more severe of the operating or the bolting-up condition so that

$$\left.\begin{aligned} M_O &= M_{op} \\ \text{or } M_O &= \frac{S_{FO}}{S_{FA}} M_{atm} \end{aligned}\right\} \text{ whichever is larger.}$$

4.7.1 For integral-type flanges and hub-type flanges:

Longitudinal hub stress $S_H = \dfrac{fM}{\lambda g_1^2}$ ... (4.7)

Radial flange stress $S_R = \dfrac{(1{\cdot}333te + 1)M}{\lambda t^2}$ ... (4.8)

Tangential flange stress $S_T = \dfrac{YM}{t^2} - ZS_R$ ... (4.9)

where $M = \dfrac{M_O C_F}{B}$

4.7.2 For loose-type ring flanges (including optional type calculated as loose ring type) having a rectangular cross section:

$$S_T = \frac{YM}{t^2} \qquad \ldots (4.10)$$

$$S_R = S_H = 0$$

where $M = \dfrac{M_O C_F}{B}$

4.8 Allowable Flange Stresses

4.8.1 The flange design stresses as calculated above, shall not exceed the following values:

$$S_H = 1{\cdot}5\, S_{FO}$$
$$S_R = S_{FO}$$
$$S_T = S_{FO}$$
$$1/2\,(S_H + S_R) = S_{FO}$$
$$1/2\,(S_H + S_T) = S_{FO}$$

4.8.2 *Weld Shear Stress* — In the case of loose-type flanges with laps, as shown in Fig. 4.1A where the gasket is so located that the lap is subjected to shear, the shearing stress shall not exceed 0·8 times S_{FO} or S_{FA} for gasket seating and operating condition respectively for the material of the lap, as defined in **4.4**. In the case of welded flanges, shown in Fig. 4.1C, D, G, H, H1 and H2 where the nozzle neck, vessel or pipe wall extends near to the flange face and may form the gasket contact face, the shearing stress carried by the welds shall not exceed 0·8 times S_{FO} or S_{FA} for gasket seating and operating condition respectively. The shearing stress shall be calculated on the basis of H_p or W_{m2} as defined in **4.4** whichever is greater. Similar cases where flange parts are subjected to shearing stress shall be governed by the same requirements.

4.9 Flanges Subject to External Pressure — The design of flanges for external pressure only shall be based on the equations given in **4.7** for internal pressure except that for operating conditions:

$$M_{op} = H_D(h_D - h_G) + H_T(h_T - h_G) \quad \ldots (4.11)$$

for gasket seating $M_{atm} = Wh_G$ ...(4.12)

in the above equations $W = \dfrac{A_{m2} + A_b}{2} \times S_a$

$$H_D = \pi/400\, B^2 p_e$$
$$H_T = H - H_D$$
$$H = \pi/400\, G^2 p_e$$

p_e = external design pressure, kgf/cm².

NOTE — The combined force of external pressure and bolt loading may plastically deform certain gaskets to result in loss of gasket contact pressure when the connection is depressurized. To maintain a tight joint when the unit is repressurized, consideration should be given to gasket and facing details, so that excessive deformation of the gasket will not occur. Joints subject to pressure reversals, such as in heat exchanger floating heads, are in this type of service.

5. PRESSURE RELIEVING DEVICES

5.1 General

5.1.1 Every pressure vessel covered by this code shall be provided with a pressure relieving device in accordance with the provisions of this section, except where otherwise provided for as in **5.1.1.1**.

5.1.1.1 When the source of the pressure is external to the vessel and under such positive control that the pressure in the vessel cannot exceed the maximum working pressure for the vessel at the operating temperature, a pressure relief device need not be directly provided on the vessel.

5.1.2 Vessels that are to operate completely filled with the liquid shall be equipped with a liquid relief valve unless otherwise protected against over-pressure.

5.1.3 When a vessel is fitted with a heating coil or element whose failure might increase the normal pressure in the vessel, the designed relieving capacity of the protective device shall be adequate to prevent this increase.

5.1.4 Vessels intended to operate under vacuum conditions, unless designed for full vacuum, shall be provided with a vacuum break relief device.

5.1.5 Vessels intended for internal pressure, but which are likely to be subjected to partial vacuum, say, due to the cooling of contents, shall be provided with a combined pressure-vacuum relief device unless the vessel is designed for full vacuum.

TABLE 4.4 VALUES OF *T*, *Z*, *Y* AND *U* (TERMS INVOLVING *K*)

K	T	Z	Y	U	K	T	Z	Y	U	K	T	Z	Y	U
1·001	1·91	1000·50	1899·43	2078·85	1·061	1·89	16·91	32·55	35·78	1·121	1·87	8·79	17·00	18·68
1·002	1·91	500·50	951·81	1052·80	1·062	1·89	16·64	32·04	35·21	1·122	1·87	8·72	16·87	18·54
1·003	1·91	333·83	637·56	700·80	1·063	1·89	16·40	31·55	34·68	1·123	1·87	8·66	16·74	18·40
1·004	1·91	250·50	478·04	525·45	1·064	1·89	16·15	31·08	34·17	1·124	1·87	8·59	16·62	18·26
1·005	1·91	200·50	383·67	421·72	1·065	1·89	15·90	30·61	33·65	1·125	1·87	8·53	16·49	18·11
1·006	1·91	167·17	319·71	351·42	1·066	1·89	15·67	30·17	33·17	1·126	1·87	8·47	16·37	17·99
1·007	1·91	143·36	274·11	301·30	1·067	1·89	15·45	29·74	32·69	1·127	1·87	8·40	16·25	17·86
1·008	1·91	125·50	239·95	263·75	1·068	1·89	15·22	29·32	32·22	1·128	1·87	8·34	16·14	17·73
1·009	1·91	111·61	213·40	234·42	1·069	1·89	15·02	28·91	31·79	1·129	1·87	8·28	16·02	17·60
1·010	1·91	100·50	192·19	211·19	1·070	1·89	14·80	28·51	31·34	1·130	1·87	8·22	15·91	17·48
1·011	1·91	91·41	174·83	192·13	1·071	1·89	14·61	28·13	30·92	1·131	1·87	8·16	15·79	17·35
1·012	1·91	83·84	160·38	176·25	1·072	1·89	14·41	27·76	30·51	1·132	1·87	8·11	15·68	17·24
1·013	1·91	77·43	148·06	162·81	1·073	1·89	14·22	27·39	30·11	1·133	1·86	8·05	15·57	17·11
1·014	1·91	71·93	137·69	151·30	1·074	1·88	14·04	27·04	29·72	1·134	1·86	7·99	15·46	16·99
1·015	1·91	67·17	128·61	141·33	1·075	1·88	13·85	26·69	29·34	1·135	1·86	7·94	15·36	16·90
1·016	1·90	63·00	120·56	132·49	1·076	1·88	13·68	26·36	28·98	1·136	1·86	7·88	15·26	16·77
1·017	1·90	59·33	111·98	124·81	1·077	1·88	13·56	26·03	28·69	1·137	1·86	7·83	15·15	16·65
1·018	1·90	56·06	107·36	118·00	1·078	1·88	13·35	25·72	28·27	1·138	1·86	7·78	15·05	16·54
1·019	1·90	53·14	101·72	111·78	1·079	1·88	13·18	25·40	27·92	1·139	1·86	7·73	14·95	16·43
1·020	1·90	50·51	96·73	106·30	1·080	1·88	13·02	25·10	27·59	1·140	1·86	7·68	14·86	16·35
1·021	1·90	48·12	92·21	101·33	1·081	1·88	12·87	24·81	27·27	1·141	1·86	7·62	14·76	16·22
1·022	1·90	45·96	88·04	96·75	1·082	1·88	12·72	24·52	26·95	1·142	1·86	7·57	14·66	16·11
1·023	1·90	43·98	84·30	92·64	1·083	1·88	12·57	24·24	26·65	1·143	1·86	7·53	14·57	16·01
1·024	1·90	42·17	80·81	88·81	1·084	1·88	12·43	24·00	26·34	1·144	1·86	7·48	14·48	15·91
1·025	1·90	40·51	77·61	85·29	1·085	1·88	12·29	23·69	26·05	1·145	1·86	7·43	14·39	15·81
1·026	1·90	38·97	74·70	82·09	1·086	1·88	12·15	23·44	25·57	1·146	1·86	7·38	14·29	15·71
1·027	1·90	37·54	71·97	79·08	1·087	1·88	12·02	23·18	25·48	1·147	1·86	7·34	14·20	15·61
1·028	1·90	36·22	69·43	76·30	1·088	1·88	11·89	22·93	25·20	1·148	1·86	7·29	14·12	15·51
1·029	1·90	34·99	67·11	73·75	1·089	1·88	11·76	22·68	24·93	1·149	1·86	7·25	14·03	15·42
1·030	1·90	33·84	64·91	71·33	1·090	1·88	11·63	22·44	24·66	1·150	1·86	7·20	13·95	15·34
1·031	1·90	32·76	62·85	69·06	1·091	1·88	11·52	22·22	24·41	1·151	1·86	7·16	13·86	15·23
1·032	1·90	31·76	60·92	66·94	1·092	1·88	11·40	21·99	24·16	1·152	1·86	7·11	13·77	15·14
1·033	1·90	30·81	59·11	63·95	1·093	1·88	11·28	21·76	23·91	1·153	1·86	7·07	13·69	15·05
1·034	1·90	29·92	57·41	63·08	1·094	1·88	11·16	21·54	23·67	1·154	1·86	7·03	13·61	14·96
1·035	1·90	29·08	55·80	61·32	1·095	1·88	11·05	21·32	23·44	1·155	1·86	6·99	13·54	14·87
1·036	1·90	28·29	54·29	59·66	1·096	1·88	10·94	21·11	23·20	1·156	1·86	6·95	13·45	14·78
1·037	1·90	27·54	52·85	58·08	1·097	1·88	10·83	20·91	22·97	1·157	1·86	6·91	13·37	14·70
1·038	1·90	26·83	51·50	56·59	1·098	1·88	10·73	20·71	22·75	1·158	1·86	6·87	13·30	14·61
1·039	1·90	26·15	50·21	55·17	1·099	1·88	10·62	20·51	22·39	1·159	1·86	6·83	13·22	14·53
1·040	1·90	25·51	48·97	53·82	1·100	1·88	10·52	20·31	22·18	1·160	1·86	6·79	13·15	14·45
1·041	1·90	24·90	47·81	53·10	1·101	1·88	10·43	20·15	22·12	1·161	1·85	6·75	13·07	14·36
1·042	1·90	24·32	46·71	51·33	1·102	1·88	10·33	19·94	21·92	1·162	1·85	6·71	13·00	14·28
1·043	1·90	23·77	45·64	50·15	1·103	1·88	10·23	19·76	21·72	1·163	1·85	6·67	12·92	14·20
1·044	1·90	23·23	44·64	49·05	1·104	1·88	10·14	19·58	21·52	1·164	1·85	6·64	12·85	14·12
1·045	1·90	22·74	43·69	48·02	1·105	1·88	10·05	19·38	21·30	1·165	1·85	6·60	12·78	14·04
1·046	1·90	22·05	42·75	46·99	1·106	1·88	9·96	19·33	21·14	1·166	1·85	6·56	12·71	13·97
1·047	1·90	21·79	41·87	46·03	1·107	1·87	9·87	19·07	20·96	1·167	1·85	6·53	12·64	13·89
1·048	1·90	21·35	41·02	45·09	1·108	1·87	9·78	18·90	20·77	1·168	1·85	6·49	12·58	13·82
1·049	1·90	20·92	40·21	44·21	1·109	1·87	9·70	18·74	20·59	1·169	1·85	6·46	12·51	13·74
1·050	1·89	20·51	39·43	43·34	1·110	1·87	9·62	18·55	20·38	1·170	1·85	6·42	12·43	13·66
1·051	1·89	20·12	38·68	42·51	1·111	1·87	9·54	18·42	20·25	1·171	1·85	6·39	12·38	13·60
1·052	1·89	19·74	37·96	41·73	1·112	1·87	9·46	18·27	20·08	1·172	1·85	6·35	12·31	13·53
1·053	1·89	19·38	37·27	40·96	1·113	1·87	9·38	18·13	19·91	1·173	1·85	6·32	12·25	13·46
1·054	1·89	19·03	36·60	40·23	1·114	1·87	9·30	17·97	19·75	1·174	1·85	6·29	12·18	13·39
1·055	1·89	18·69	35·96	39·64	1·115	1·87	9·22	17·81	19·55	1·175	1·85	6·25	12·10	13·30
1·056	1·89	18·38	35·34	38·84	1·116	1·87	9·15	17·68	19·43	1·176	1·85	6·22	12·06	13·25
1·057	1·89	18·06	34·74	38·19	1·117	1·87	9·07	17·54	19·27	1·177	1·85	6·19	12·00	13·18
1·058	1·89	17·76	34·17	37·56	1·118	1·87	9·00	17·40	19·12	1·178	1·85	6·16	11·93	13·11
1·059	1·89	17·47	33·62	36·95	1·119	1·87	8·94	17·27	18·98	1·179	1·85	6·13	11·87	13·05
1·060	1·89	17·18	33·64	36·34	1·120	1·87	8·86	17·13	18·80	1·180	1·85	6·10	11·79	12·96

(*Continued*)

TABLE 4.4 VALUES OF T, Z, Y AND U (TERMS INVOLVING K) — *Contd*

K	T	Z	Y	U	K	T	Z	Y	U	K	T	Z	Y	U
1·181	1·85	6·07	11·76	12·92	1·241	1·82	4·70	9·12	10·02	1·301	1·80	3·89	7·53	8·27
1·182	1·85	6·04	11·70	12·86	1·242	1·82	4·69	9·08	9·98	1·302	1·80	3·88	7·50	8·24
1·183	1·85	6·01	11·64	12·79	1·243	1·82	4·67	9·05	9·95	1·303	1·80	3·87	7·48	8·22
1·184	1·85	5·98	11·58	12·73	1·244	1·82	4·65	9·02	9·91	1·304	1·80	3·86	7·46	8·20
1·185	1·85	5·95	11·50	12·64	1·245	1·82	4·64	8·99	9·87	1·305	1·80	3·84	7·44	8·18
1·186	1·85	5·92	11·47	12·61	1·246	1·82	4·62	8·95	9·84	1·306	1·80	3·83	7·42	8·16
1·187	1·85	5·89	11·42	12·54	1·247	1·82	4·60	8·92	9·81	1·307	1·80	3·82	7·40	8·13
1·188	1·85	5·86	11·36	12·49	1·248	1·82	4·59	8·89	9·77	1·308	1·79	3·81	7·38	8·11
1·189	1·85	5·83	11·31	12·43	1·249	1·82	4·57	8·86	9·74	1·309	1·79	3·80	7·36	8·09
1·190	1·84	5·81	11·26	12·37	1·250	1·82	4·56	8·83	9·70	1·310	1·79	3·79	7·34	8·07
1·191	1·84	5·78	11·20	12·31	1·251	1·82	4·54	8·80	9·67	1·311	1·79	3·78	7·32	8·05
1·192	1·84	5·75	11·15	12·25	1·252	1·82	4·52	8·77	9·64	1·312	1·79	3·77	7·30	8·02
1·193	1·84	5·73	11·10	12·20	1·253	1·82	4·51	8·74	9·60	1·313	1·79	3·76	7·28	8·00
1·194	1·84	5·70	11·05	12·14	1·254	1·82	4·49	8·71	9·57	1·314	1·79	3·75	7·26	7·98
1·195	1·84	5·67	11·00	12·08	1·255	1·82	4·48	8·68	9·54	1·315	1·79	3·74	7·24	7·96
1·196	1·84	5·65	10·95	12·03	1·256	1·82	4·46	8·65	9·51	1·316	1·79	3·73	7·22	7·94
1·197	1·84	5·62	10·90	11·97	1·257	1·82	4·45	8·62	9·47	1·317	1·79	3·72	7·20	7·92
1·198	1·84	5·60	10·85	11·92	1·258	1·81	4·43	8·59	9·44	1·318	1·79	3·71	7·18	7·89
1·199	1·84	5·57	10·80	11·87	1·259	1·81	4·42	8·56	9·41	1·319	1·79	3·70	7·16	7·87
1·200	1·84	5·55	10·75	11·81	1·260	1·81	4·40	8·53	9·38	1·320	1·79	3·69	7·14	7·85
1·201	1·84	5·52	10·70	11·76	1·261	1·81	4·39	8·51	9·35	1·321	1·79	3·68	7·12	7·83
1·202	1·84	5·50	10·65	11·71	1·262	1·81	4·37	8·49	9·32	1·322	1·79	3·67	7·10	7·81
1·203	1·84	5·47	10·61	11·66	1·263	1·81	4·36	8·45	9·28	1·323	1·79	3·67	7·09	7·79
1·204	1·84	5·45	10·56	11·61	1·264	1·81	4·35	8·42	9·25	1·324	1·79	3·66	7·07	7·77
1·205	1·84	5·42	10·52	11·56	1·265	1·81	4·33	8·39	9·23	1·325	1·79	3·65	7·05	7·75
1·206	1·84	5·40	10·47	11·51	1·266	1·81	4·32	8·37	9·19	1·326	1·79	3·64	7·03	7·73
1·207	1·84	5·38	10·43	11·46	1·267	1·81	4·30	8·34	9·16	1·327	1·79	3·63	7·01	7·71
1·208	1·84	5·35	10·38	11·41	1·268	1·81	4·29	8·31	9·14	1·328	1·78	3·62	7·00	7·69
1·209	1·84	5·33	10·34	11·36	1·269	1·81	4·28	8·29	9·11	1·329	1·78	3·61	6·98	7·67
1·210	1·84	5·31	10·30	11·32	1·270	1·81	4·26	8·26	9·08	1·330	1·78	3·60	6·96	7·65
1·211	1·83	5·29	10·25	11·27	1·271	1·81	4·25	8·23	9·05	1·331	1·78	3·59	6·94	7·63
1·212	1·83	5·27	10·21	11·22	1·272	1·81	4·24	8·21	9·02	1·332	1·78	3·58	6·92	7·61
1·213	1·83	5·24	10·16	11·17	1·273	1·81	4·22	8·18	8·99	1·333	1·78	3·57	6·91	7·59
1·214	1·83	5·22	10·12	11·12	1·274	1·81	4·21	8·15	8·96	1·334	1·78	3·57	6·89	7·57
1·215	1·83	5·20	10·09	11·09	1·275	1·81	4·20	8·13	8·93	1·335	1·78	3·56	6·87	7·55
1·216	1·83	5·18	10·04	11·03	1·276	1·81	4·18	8·11	8·91	1·336	1·78	3·55	6·85	7·53
1·217	1·83	5·16	10·00	10·99	1·277	1·81	4·17	8·08	8·88	1·337	1·78	3·54	6·84	7·51
1·218	1·83	5·14	9·96	10·94	1·278	1·81	4·16	8·05	8·85	1·338	1·78	3·53	6·82	7·50
1·219	1·83	5·12	9·92	10·90	1·279	1·81	4·15	8·03	8·82	1·339	1·78	3·52	6·81	7·48
1·220	1·83	5·10	9·89	10·87	1·280	1·81	4·13	8·01	8·79	1·340	1·78	3·51	6·79	7·46
1·221	1·83	5·07	9·84	10·81	1·281	1·81	4·12	7·98	8·77	1·341	1·78	3·51	6·77	7·44
1·222	1·83	5·05	9·80	10·77	1·282	1·81	4·11	7·96	8·74	1·342	1·78	3·50	6·76	7·42
1·223	1·83	5·03	9·76	10·73	1·283	1·80	4·10	7·93	8·71	1·343	1·78	3·49	6·74	7·41
1·224	1·83	5·01	9·72	10·68	1·284	1·80	4·08	7·91	8·69	1·344	1·78	3·48	6·72	7·39
1·225	1·83	5·00	9·69	10·65	1·285	1·80	4·07	7·89	8·66	1·345	1·78	3·47	6·71	7·37
1·226	1·83	4·98	9·65	10·60	1·286	1·80	4·06	7·86	8·64	1·346	1·78	3·46	6·69	7·35
1·227	1·83	4·96	9·61	10·56	1·287	1·80	4·05	7·84	8·61	1·347	1·78	3·46	6·68	7·33
1·228	1·83	4·94	9·57	10·52	1·288	1·80	4·04	7·81	8·59	1·348	1·78	3·45	6·66	7·32
1·229	1·83	4·92	9·53	10·48	1·289	1·80	4·02	7·79	8·56	1·349	1·78	3·44	6·65	7·30
1·230	1·83	4·90	9·50	10·44	1·290	1·80	4·01	7·77	8·53	1·350	1·78	3·43	6·63	7·28
1·231	1·83	4·88	9·46	10·40	1·291	1·80	4·00	7·75	8·51	1·351	1·78	3·42	6·61	7·27
1·232	1·83	4·86	9·43	10·36	1·292	1·80	3·99	7·72	8·48	1·352	1·78	3·42	6·60	7·25
1·233	1·83	4·84	9·39	10·32	1·293	1·80	3·98	7·70	8·46	1·353	1·77	3·41	6·58	7·23
1·234	1·83	4·83	9·36	10·28	1·294	1·80	3·97	7·68	8·43	1·354	1·77	3·40	6·57	7·21
1·235	1·83	4·81	9·32	10·24	1·295	1·80	3·95	7·66	8·41	1·355	1·77	3·39	6·55	7·19
1·236	1·82	4·79	9·29	10·20	1·296	1·80	3·94	7·63	8·39	1·356	1·77	3·38	6·53	7·17
1·237	1·82	4·77	9·25	10·17	1·297	1·80	3·93	7·61	8·36	1·357	1·77	3·38	6·52	7·16
1·238	1·82	4·76	9·22	10·13	1·298	1·80	3·92	7·59	8·33	1·358	1·77	3·37	6·50	7·14
1·239	1·82	4·74	9·18	10·09	1·299	1·80	3·91	7·57	8·31	1·359	1·77	3·36	6·49	7·12
1·240	1·82	4·72	9·15	10·05	1·300	1·80	3·90	7·55	8·29	1·360	1·77	3·35	6·47	7·11

(*Continued*)

TABLE 4.4 VALUES OF *T*, *Z*, *Y* AND *U* (TERMS INVOLVING *K*) — *Contd*

K	*T*	*Z*	*Y*	*U*	*K*	*T*	*Z*	*Y*	*U*	*K*	*T*	*Z*	*Y*	*U*
1·361	1·77	3·35	6·45	7·09	1·421	1·75	2·96	5·69	6·26	1·481	1·72	2·68	5·11	5·60
1·362	1·77	3·34	6·44	7·08	1·422	1·75	2·96	5·68	6·25	1·482	1·72	2·67	5·10	5·59
1·363	1·77	3·33	6·42	7·06	1·423	1·75	2·95	5·67	6·23	1·483	1·72	2·67	5·10	5·59
1·364	1·77	3·32	6·41	7·04	1·424	1·74	2·95	5·66	6·22	1·484	1·72	2·66	5·09	5·58
1·365	1·77	3·32	6·39	7·03	1·425	1·74	2·94	5·65	6·21	1·485	1·72	2·66	5·08	5·57
1·366	1·77	3·31	6·38	7·01	1·426	1·74	2·94	5·64	6·20	1·486	1·72	2·66	5·07	5·56
1·367	1·77	3·30	6·37	7·00	1·427	1·74	2·93	5·63	6·19	1·487	1·72	2·65	5·06	5·55
1·368	1·77	3·30	6·35	6·98	1·428	1·74	2·92	5·62	6·17	1·488	1·72	2·65	5·06	5·55
1·369	1·77	3·29	6·34	6·97	1·429	1·74	2·92	5·61	6·16	1·489	1·72	2·64	5·05	5·54
1·370	1·77	3·28	6·32	6·95	1·430	1·74	2·91	5·60	6·15	1·490	1·72	2·64	5·04	5·53
1·371	1·77	3·27	6·31	6·93	1·431	1·74	2·91	5·59	6·14	1·491	1·72	2·64	5·03	5·52
1·372	1·77	3·27	6·30	6·91	1·432	1·74	2·90	5·58	6·13	1·492	1·72	2·63	5·02	5·51
1·373	1·77	3·26	6·28	6·90	1·433	1·74	2·90	5·57	6·11	1·493	1·71	2·63	5·02	5·51
1·374	1·77	3·25	6·27	6·89	1·434	1·74	2·89	5·56	6·10	1·494	1·71	2·62	5·01	5·50
1·375	1·77	3·25	6·25	6·87	1·435	1·74	2·89	5·55	6·09	1·495	1·71	2·62	5·00	5·49
1·376	1·77	3·24	6·24	6·86	1·436	1·74	2·88	5·54	6·08	1·496	1·71	2·62	4·99	5·48
1·377	1·77	3·23	6·22	6·84	1·437	1·74	2·88	5·53	6·07	1·497	1·71	2·61	4·98	5·47
1·378	1·76	3·22	6·21	6·82	1·438	1·74	2·87	5·52	6·05	1·498	1·71	2·61	4·98	5·47
1·379	1·76	3·22	6·19	6·81	1·439	1·74	2·87	5·51	6·04	1·499	1·71	2·60	4·97	5·46
1·380	1·76	3·21	6·18	6·80	1·440	1·74	2·86	5·50	6·03	1·500	1·71	2·60	4·96	5·45
1·381	1·76	3·20	6·17	6·79	1·441	1·74	2·86	5·49	6·02	1·501	1·71	2·60	4·95	5·44
1·382	1·76	3·20	6·16	6·77	1·442	1·74	2·85	5·48	6·01	1·502	1·71	2·59	4·94	5·43
1·383	1·76	3·19	6·14	6·75	1·443	1·74	2·85	5·47	6·00	1·503	1·71	2·59	4·94	5·43
1·384	1·76	3·18	6·13	6·74	1·444	1·74	2·84	5·46	5·99	1·504	1·71	2·58	4·93	5·42
1·385	1·76	3·18	6·12	6·73	1·445	1·74	2·84	5·45	5·98	1·505	1·71	2·58	4·92	5·41
1·386	1·76	3·17	6·11	6·72	1·446	1·74	2·83	5·44	5·97	1·506	1·71	2·58	4·91	5·40
1·387	1·76	3·16	6·10	6·70	1·447	1·73	2·83	5·43	5·96	1·507	1·71	2·57	4·90	5·39
1·388	1·76	3·16	6·08	6·68	1·448	1·73	2·82	5·42	5·95	1·508	1·71	2·57	4·90	5·39
1·389	1·76	3·15	6·07	6·67	1·449	1·73	2·82	5·41	5·94	1·509	1·71	2·57	4·89	5·38
1·390	1·76	3·15	6·06	6·66	1·450	1·73	2·81	5·40	5·93	1·510	1·71	2·56	4·88	5·37
1·391	1·76	3·14	6·05	6·64	1·451	1·73	2·81	5·39	5·92	1·511	1·71	2·56	4·87	5·36
1·392	1·76	3·13	6·04	6·63	1·452	1·73	2·80	5·38	5·91	1·512	1·71	2·56	4·86	5·35
1·393	1·76	3·13	6·02	6·61	1·453	1·73	2·80	5·37	5·90	1·513	1·71	2·55	4·86	5·35
1·394	1·76	3·12	6·01	6·60	1·454	1·73	2·80	5·36	5·89	1·514	1·71	2·55	4·85	5·34
1·395	1·76	3·11	6·00	6·59	1·455	1·73	2·79	5·35	5·88	1·515	1·71	2·54	4·84	5·33
1·396	1·76	3·11	5·99	6·58	1·456	1·73	2·79	5·34	5·87	1·516	1·71	2·54	4·83	5·32
1·397	1·76	3·10	5·98	6·56	1·457	1·73	2·78	5·33	5·86	1·517	1·71	2·54	4·82	5·31
1·398	1·75	3·10	5·96	6·55	1·458	1·73	2·78	5·32	5·85	1·518	1·71	2·53	4·82	5·31
1·399	1·75	3·09	5·95	6·53	1·459	1·73	2·77	5·31	5·84	1·519	1·70	2·53	4·81	5·30
1·400	1·75	3·08	5·94	6·52	1·460	1·73	2·77	5·30	5·83	1·520	1·70	2·53	4·80	5·29
1·401	1·75	3·08	5·93	6·50	1·461	1·73	2·76	5·29	5·82	1·521	1·70	2·52	4·79	5·28
1·402	1·75	3·07	5·92	6·49	1·462	1·73	2·76	5·28	5·80	1·522	1·70	2·52	4·79	5·27
1·403	1·75	3·07	5·90	6·47	1·463	1·73	2·75	5·27	5·79	1·523	1·70	2·52	4·78	5·27
1·404	1·75	3·06	5·89	6·46	1·464	1·73	2·75	5·26	5·78	1·524	1·70	2·51	4·78	5·26
1·405	1·75	3·05	5·88	6·45	1·465	1·73	2·74	5·25	5·77	1·525	1·70	2·51	4·77	5·25
1·406	1·75	3·05	5·87	6·44	1·466	1·73	2·74	5·24	5·76	1·526	1·70	2·51	4·77	5·24
1·407	1·75	3·04	5·86	6·43	1·467	1·73	2·74	5·23	5·74	1·527	1·70	2·50	4·76	5·23
1·408	1·75	3·04	5·84	6·41	1·468	1·72	2·73	5·22	5·73	1·528	1·70	2·50	4·76	5·23
1·409	1·75	3·03	5·83	6·40	1·469	1·72	2·73	5·21	5·72	1·529	1·70	2·49	4·75	5·22
1·410	1·75	3·02	5·82	6·39	1·470	1·72	2·72	5·20	5·71	1·530	1·70	2·49	4·74	5·21
1·411	1·75	3·02	5·81	6·38	1·471	1·72	2·72	5·19	5·70	1·531	1·70	2·49	4·73	5·20
1·412	1·75	3·01	5·80	6·37	1·472	1·72	2·71	5·18	5·69	1·532	1·70	2·48	4·72	5·19
1·413	1·75	3·01	5·78	6·35	1·473	1·72	2·71	5·18	5·68	1·533	1·70	2·48	4·72	5·19
1·414	1·75	3·00	5·77	6·34	1·474	1·72	2·71	5·17	5·67	1·534	1·70	2·48	4·71	5·17
1·415	1·75	3·00	5·76	6·33	1·475	1·72	2·70	5·16	5·66	1·535	1·70	2·47	4·70	5·17
1·416	1·75	2·99	5·75	6·32	1·476	1·72	2·70	5·15	5·65	1·536	1·70	2·47	4·69	5·16
1·417	1·75	2·98	5·74	6·31	1·477	1·72	2·69	5·14	5·64	1·537	1·70	2·47	4·68	5·15
1·418	1·75	2·98	5·72	6·29	1·478	1·72	2·69	5·14	5·63	1·538	1·69	2·46	4·68	5·15
1·419	1·75	2·97	5·71	6·28	1·479	1·72	2·68	5·13	5·62	1·539	1·69	2·46	4·67	5·14
1·420	1·75	2·97	5·70	6·27	1·480	1·72	2·68	5·12	5·61	1·540	1·69	2·46	4·66	5·13

(*Continued*)

TABLE 4.4 VALUES OF T, Z, Y AND U (TERMS INVOLVING K) — *Contd*

K	T	Z	Y	U	K	T	Z	Y	U	K	T	Z	Y	U
1·541	1·69	2·45	4·66	5·12	1·556	1·69	2·41	4·57	5·02	1·571	1·68	2·36	4·47	4·91
1·542	1·69	2·45	4·65	5·11	1·557	1·69	2·40	4·56	5·01	1·572	1·68	2·36	4·47	4·91
1·543	1·69	2·45	4·64	5·11	1·558	1·69	2·40	4·56	5·00	1·573	1·68	2·36	4·46	4·90
1·544	1·69	2·45	4·64	5·10	1·559	1·69	2·40	4·55	4·99	1·574	1·68	2·35	4·46	4·89
1·545	1·69	2·44	4·63	5·09	1·560	1·69	2·40	4·54	4·99	1·575	1·68	2·35	4·45	4·89
1·546	1·69	2·44	4·63	5·08	1·561	1·69	2·39	4·54	4·98	1·576	1·68	2·35	4·44	4·88
1·547	1·69	2·44	4·62	5·07	1·562	1·69	2·39	4·53	4·97	1·577	1·68	2·35	4·44	4·88
1·548	1·69	2·43	4·62	5·07	1·563	1·68	2·39	4·52	4·97	1·578	1·68	2·34	4·43	4·87
1·549	1·69	2·43	4·61	5·06	1·564	1·68	2·38	4·51	4·96	1·579	1·68	2·34	4·42	4·86
1·550	1·69	2·43	4·60	5·05	1·565	1·68	2·38	4·51	4·95	1·580	1·68	2·34	4·42	4·86
1·551	1·69	2·42	4·60	5·05	1·566	1·68	2·38	4·50	4·95					
1·552	1·69	2·42	4·59	5·04	1·567	1·68	2·37	4·50	4·94					
1·553	1·69	2·42	4·58	5·03	1·568	1·68	2·37	4·49	4·93					
1·554	1·69	2·41	4·58	5·03	1·569	1·68	2·37	4·48	4·92					
1·555	1·69	2·41	4·57	5·02	1·570	1·68	2·37	4·48	4·92					

TABLE 4.5 ALLOWABLE STRESSES FOR FLANGE BOLTING MATERIAL kgf/mm²

Material	Diameter (mm)	Specified Tensile Strength (kgf/mm²)	Allowable Stress kgf/mm² for Design Metal Temperature Not Exceeding (°C)						
			50	100	200	250	300	350	400
Hot rolled carbon steel	Up to 150	44-52	5·87	5·62	5·45	4·85	—	—	—
1% Cr Mo steel	Up to 63·5	86 *Min*	19·68	18·5	17·1	16·2	15·75	15·12	14·27
	Over 63·5 to 102	79 *Min*	17·79	16·66	15·47	14·76	14·41	13·71	12·94
5% Cr Mo steel	Up to 63·5 over 63·5 Up to 102	71 *Min* 66 *Min*	14·06	14·06	14·06	14·06	14·06	14·06	14·06
1% Cr Mo V steel	Up to 63·5	86 *Min*	19·68	19·05	18·49	17·93	17·29	16·80	16·03
	Over 63·5 up to 102	82 *Min*	17·79	17·23	16·66	16·24	15·54	15·26	14·55
13% Cr Ni steel	Up to 102	71 *Min*	17·93	16·45	14·34	13·64	12·86	12·16	10·65
18/8 Cr Ni steel	All (1) (2)	55 *Min* in softened condition or up to 88 *Min* if cold drawn	13·18	11·07	8·65	8·01	7·73	7·45	7·31
18/8 Cr Ni Ti stabilized steel	All (1) (2)		13·18	11·53	10·19	9·49	9·14	8·79	8·58
18/9 Cr Ni Nb stabilized steel	All (1) (2)		13·18	11·53	10·19	9·49	9·14	8·79	8·58
17/10/2½ Cr Ni Mo steel	All (1) (2)		13·18	11·18	9·56	8·86	8·51	8·08	7·94
18 Cr 2 Ni steel	Up to 102	86 *Min*	21·58	19·90	17·30	16·40	15·54	14·69	12·94

NOTE 1 — Austenitic steel bolts for use in pressure joints shall not be less than 10 mm diameter.

NOTE 2 — For bolts up to 38 mm diameter torque spanners or other means of preventing the application of excessive stress during tightening are necessary.

NOTE 3 — High strengths are obtainable in bolting materials by heat treatment of the ferritic and martensitic steels and by cold working of austenitic steels. These should not, however, be used for bolting with tensile strengths greater than 110 kgf/mm² (ferritic and martensitic) or 100 kgf/mm² (austenitic) unless special agreement is reached between the purchaser and the manufacturer.

NOTE 4 — Other suitable materials may be used for bolting by agreement between the purchaser and the manufacturer.

5.2 Design

5.2.1 The protective device used shall be suitable for the conditions of service and shall be adequate for duty.

5.2.1.1 In general, relief valves are preferred for vessel protection but bursting discs or a combination of relief valves and bursting discs may be preferable in certain circumstances (*see* **5.2.3.1**).

5.2.2 *Relief Valves*

5.2.2.1 Spring loaded relief valves are preferred but other types like valves fitted with a weight or with lever and weight loading are acceptable, provided that they are equally safe.

5.2.2.2 Pilot valve control or other indirect operation of relief valves is not permitted unless the design is such that the main valve will open automatically at the set pressure and discharge to the full capacity, should the pilot or auxiliary device fail.

5.2.2.3 The relief valves shall be so designed that they cannot be inadvertently loaded beyond the set pressure.

5.2.2.4 The design of valves shall be such that breakage of any part will not obstruct the free and full discharge of the fluid under pressure.

5.2.3 *Bursting Discs*

5.2.3.1 The use of a bursting disc as a pressure relieving device is preferred:

a) where pressure rise may be so rapid as to be analogous to combustion or explosion, so that the inertia of a relief valve would be a disadvantage;
b) where service conditions may involve heavy deposits or gumming up, such as would render a relief valve inoperative; and
c) where even minute leakage of fluid cannot be tolerated.

5.2.3.2 Bursting discs may be mounted in series with a relief valve provided that:

a) the maximum pressure of the range for which the disc is designed to burst does not exceed the maximum working pressure of the vessel;
b) the opening provided through the disc after breakage is sufficient to prevent interference with the proper functioning of the relief valve; and
c) in case of a bursting disc fitted on the discharge side of a valve, back pressure cannot be built up and so influence the lifting pressure of the valve.

5.2.3.3 Every bursting disc shall have a specified and certified bursting pressure at a specified temperature and shall be marked in accordance with **5.3.2.** It shall be certified by the manufacturer to burst within ± 5 percent of its certified bursting pressure at the specified temperature.

5.3 Marking

5.3.1 *Relief Valves* — Every relief valve shall incorporate permanent marking as follows:

a) Manufacturer's identification,
b) Nominal inlet and outlet sizes,
c) Design pressure and temperature, and
d) Certified capacity in kilograms of saturated steam per hour or in the case of liquid relief certified capacity in litres of water per minute.

5.3.2 *Bursting Discs*

5.3.2.1 The bursting discs shall be stamped with the following information:

a) Manufacturer's identification
b) Size
c) Bursting pressure
d) Coincident disc temperature, and
e) Capacity at discharge

Unless the size of the disc is insufficient in which case the disc shall be contained in a sealed envelope prior to the installation and the envelope shall be clearly marked with the above information.

5.3.2.2 A register of bursting disc data shall be kept by the user for each vessel protected by a bursting disc. The register shall relate the service conditions at which the vessel operates to the serial letters and numbers stamped on the disc or marked on the envelope in which the disc was contained.

5.4 Capacity of Relief Valves

5.4.1 The relief valve shall be of sufficient capacity to discharge the maximum quantity of the fluid contained in the vessel without permitting a rise in the vessel pressure of more than 10 percent above the set pressure when they are discharging.

5.4.2 *Vapour Relief* — The capacity of a relief valve in terms of a gas or vapour other than steam, which is the manufacturer's usual rating basis, may be determined by the following equation:

$$W = CKAp\sqrt{\frac{M}{T}}$$

where

W = rated capacity in kg/h,

C = a constant for gas or vapour which is a function of the ratio of specific heats, γ (*see* Table 5.1),

C_p = specific heat at constant pressure,

C_v = specific heat at constant volume,

A = actual discharge area in mm^2,

p = accumulation pressure ($1{\cdot}10 \times$ set pressure) kgf/cm^2 abs,

M = molecular weight,

T = inlet temperature in degree Kelvin, and

K = coefficient of discharge which depends on the shape of the inlet and of the disc and lift characteristics of the valve and is specific to any particular relief valve.

TABLE 5.1 CONSTANT C FOR GAS OR VAPOUR RELATED TO RATIO OF SPECIFIC HEATS γ
($\gamma = C_p/C_v$)

γ	C	γ	C	γ	C
(1)	(2)	(1)	(2)	(1)	(2)
1·00	2·34	1·26	2·55	1·52	2·72
1·02	2·37	1·28	2·57	1·54	2·74
1·04	2·38	1·30	2·58	1·56	2·75
1·06	2·40	1·32	2·60	1·58	2·76
1·08	2·42	1·3[illegible]	2·61	1·60	2·77
1·10	2·44	1·36	2·63	1·62	2·78
1·12	2·45	1·38	2·64	1·64	2·80
1·14	2·46	1·40	2·65	1·66	2·81
1·16	2·48	1·42	2·66	1·68	2·82
1·18	2·50	1·44	2·67	1·[illegible]	2·83
1·20	2·51	1·46	2·68	2·00	2·98
1·22	2·52	1·48	2·70	2·20	3·07
1·24	2·54	1·50	2·71		

5.4.3 *Liquid Relief* — Assuming that no vaporization occurs and that the flow through the relief valve is dependent only on the pressure drop and the theoretical area, the general equation for liquid flow may be written as:

$$Q = 8{\cdot}404 \times 10^{-4}\, KA \sqrt{\frac{p}{\rho}} \text{ or } W = 50{\cdot}42\, KA\sqrt{p\rho}$$

where

Q = flow in cubic metre per minute,

W = flow in kg per hour,

p = pressure drop in kgf/cm²,

ρ = specific gravity at inlet temperature,

A = actual discharge area in mm², and

K = overall coefficient of discharge specific to any particular relief valve.

5.5 Pressure Setting of a Pressure Relieving Device

5.5.1 The pressure relieving device shall be set to operate at a pressure not exceeding the maximum working pressure of the vessel at the operating temperature. The pressure at which a relief valve is set to operate shall include the effect of static head and constant back pressure.

5.5.1.1 However, when more than one protective device is provided, only one of the valves need be set to operate at the maximum working pressure, the additional device or devices being set to discharge at a pressure not more than 5 percent in excess of the maximum working pressure provided that the total capacity is adequate.

5.6 Installation of Pressure Relieving Devices

5.6.1 Vapour relief valves and bursting discs shall be connected to the vessel in the vapour space above any entrained liquid or to piping connected to the vapour space. Liquid relief valves shall be connected below the liquid level.

5.6.2 They shall be so located that they are readily accessible for inspection and maintenance and so that they cannot readily be rendered inoperative.

5.6.3 Where for purposes of inspection and maintenance, a pressure relief device needs to be isolated from the vessel which it protects, additional valves shall be provided. Such valves shall be of approved type fitted with an approved form of locking gear. Such valve should normally be locked in the open position.

5.7 Discharge Lines

5.7.1 Where practicable, a pressure relieving device should discharge to atmosphere through a vertical pipe clear of adjacent equipment and space normally accessible to personnel. The discharge pipe shall have at least the same bore as the relieving device outlet.

5.7.2 Where discharge lines are long, or a single discharge line caters to more than one pressure relieving device, the effect of back pressure that may develop therein shall be considered for each protective device. The use of relief devices specially designed for use on high or variable back pressure is recommended.

5.7.3 Proper attention shall be paid to the drainage of discharge lines, which shall be of such a size that any pressure that may exist or develop therein will not reduce the relieving capacity of the relieving devices below that required to properly protect the vessel.

5.7.4 Discharge lines shall be securely anchored, particularly at their open ends, so that the reaction produced by the fluid being discharged on the lines, does not displace the lines from their normal positions.

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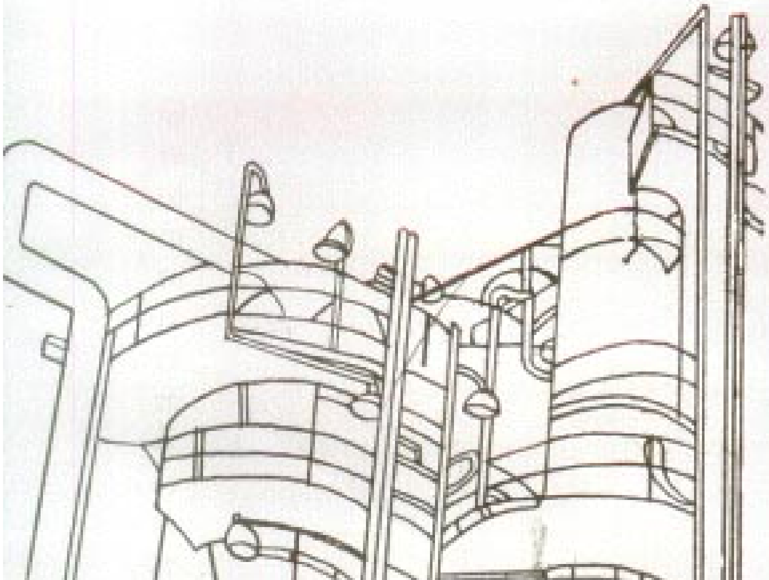
SECTION II FABRICATION AND WELDING



CODE FOR UNFIRED PRESSURE VESSELS

6. MANUFACTURE AND WORKMANSHIP
7. WELDING QUALIFICATIONS

SECTION II FABRICATION AND WELDING

6. MANUFACTURE AND WORKMANSHIP

6.1 Approval of Design — Before commencing manufacture, the manufacturer, if so required, shall submit for approval by the purchaser a fully dimensioned drawing showing the pressure portions of the vessel and carrying the following information:

a) A statement that the vessel is to be constructed to this standard.

b) Specification(s) to which materials shall conform.

c) Welding process(es) to be adopted for all parts of the vessel.

d) Large-scale dimensional details of the weld preparation for the longitudinal and circumferential seams and details of the joints for branch pipes, seatings, etc, and the position of these joints relative to the longitudinal and circumferential seams and other openings.

e) Design pressure(s) and temperature(s) and major structural loadings.

f) Test pressure(s).

g) Amount and location of corrosion allowance.

   No modification shall be made to the approved design except with prior agreement between the purchaser and the manufacturer.

h) Additional requirements, if any, specified by the purchaser.

6.2 Welded Joints, General Considerations

6.2.1 Welded construction of pressure vessels is subjected to the following general conditions.

6.2.1.1 All details of design and construction shall generally conform to the provisions of this code. (Examples of typical designs of welded connections are given in Appendix G.)

6.2.1.2 The materials shall conform to the requirements of the appropriate Indian Standards or shall be any other approved material.

6.2.1.3 The welders shall be qualified for the type of welding concerned in conformity with the welder's performance qualification (*see* **7.2**).

6.2.2 Nozzles, pads, branches, pipes, tubes, etc, and non-pressure parts may be welded to pressure parts provided that the strength and the characteristics of the material of the pressure parts are not affected adversely.

If heat treatment is mandatory under the requirements of this code, the attachment of parts mentioned above by welding shall take place before the final heat treatment.

6.2.3 The manufacturer of a pressure vessel built according to this code, shall be responsible for all the welding work done under this code.

The manufacturer shall conduct the tests required in this code (*see* **7.1** *and* **7.2**) to qualify the welding procedure employed and to judge performance of the welders who apply this procedure.

6.2.4 The manufacturer shall maintain a record of the results obtained in welding procedure qualification tests (*see* Appendix H).

These records giving an accurate description of all the particulars of the materials and procedure concerned shall be certified by him and shall be accessible to the inspecting authority who should be permitted to witness the tests if he so desires.

6.2.5 Any person who wishes to qualify for a welder's performance test under this code shall not be below the age of 18 years and shall have been employed as a welder in a workshop or firm for a period of not less than two years.

A record shall be kept to show that the welder has been employed on work of the kind covered by his performance tests, during the previous six months.

These records shall contain the results of the welder's performance tests and the identification mark assigned to each welder. They shall be certified by the manufacturer and be accessible to the inspecting authority (*see* Appendix H).

The welds made by each welder shall be marked with a stamp showing the welder's identity at intervals of one metre or less. Care shall be taken to avoid notching or stress concentration due to deep stamping of welder's identity. Deep stamping as a means of identifying welded seam is not recommended on carbon steel plates less than 7 mm thick or vessels subject to low temperatures or on austenitic and alloy steels. When deep stamping is not permitted, a record shall be kept by the manufacturers of welders and welding operators employed on each joint which shall be available to the inspecting authority; suitable stencil or other surface markings may be used additionally.

6.2.6 The inspecting authority shall have the right to disqualify a welder any time during the fabrication of a vessel, when there is a specific reason to question his ability to make welds that meet this code requirements. Such a disqualified welder at the option of the manufacturer may be put up for retests, under the conditions specified in **7.2.8.1**.

6.3 Design of Welded Joints

6.3.1 Single fillet welded lap joints should not be used without previous consent of the inspecting authority.

6.3.2 In the design of all details the aim shall be to avoid disturbances in the flow of the lines of force, in particular in constructions subjected to fatigue stresses. Holes and openings shall not be positioned on or in the heat affected zones of

welded joints. Where such openings are unavoidable, such holes can be located on circumferential joints provided the weld is radiographically sound for a length of three times the diameter of the hole on either side.

6.3.2.1 Further, welded joints should be positioned in such a manner that they are subjected to lowest possible bending stresses. Joints between cylindrical shells and domed end plates shall not be located in the curved part of the domed end (*see* Table 6.2). When dished end plates are assembled from a number of plates, the welded joints between these plates shall preferably cross the corner curvature for the shortest possible length.

6.3.2.2 Attachment of parts by welding which cross or which are in the immediate vicinity of existing main welds in pressure parts should, as far as possible, be avoided. If such welds cannot be avoided, they should cross the main weld completely rather than stop abruptly near the main weld so that stress concentrations in these areas are avoided. Further, such a part should be subjected to local radiographic examination or other approved non-destructive tests and stress relief, where necessary.

6.3.3 The entire assembly as well as the individual welded joints shall be designed after giving due consideration to the method of welding and the specific character of the joints. The aim shall be to avoid welding in difficult positions. Further, welded joints shall be so positioned that they permit visual and other methods of inspection and re-welding of the root side of the welds wherever possible. Welded joints should be free from undue restraint.

6.3.4 Concentration of welded joints should be avoided and the design should be made in such a way that no two main seams come together under an acute angle or cross each other. Where it is not possible to comply with this requirement, the intersection of the welds should be radiographed, 100 mm on each side of intersection (*see* **8.7.1** and **8.7.2**). This involves among other things that the longitudinal joints should be, wherever possible, staggered when assembling a cylindrical shell from two parts by means of a circumferential joint. The distance shall be at least five times the thickness of thicker plate.

6.3.5 Where a butt joint is required between plates which differ in thickness by more than one-fourth the thickness of thinner plate or more than 3 mm, the thicker plate shall have a tapered transition section as shown in Fig. 6.1 (*see also* Table 6.2). The transition section shall have a minimum length of four times the offset between the abutting plate edges. The transition section may be formed by any process that will provide a uniform taper. The weld may be partly or entirely in the tapered section or adjacent to it.

It is recommended that width of the parallel portion may not be less than 32 mm when the butt weld is to be radiographically examined.

6.3.6 The types of butt joints recommended for fusion welding processes (arc and gas welding), their shapes and dimensions are given in Table 6.1. The dimensions and shape of the edges shall permit complete fusion and penetration. Qualification of welding procedure as required under **7.1** is acceptable as proof that the welding groove is satisfactory.

6.3.6.1 Where butt joints welded from one side only are credited with a joint factor equal to that permitted for butt joints with backing strips, the procedure of welding should be such as to obtain the same quality of deposited weld metal on the inside and outside. The joint shall have complete joint penetration and complete fusion for the full length of the weld and shall be free

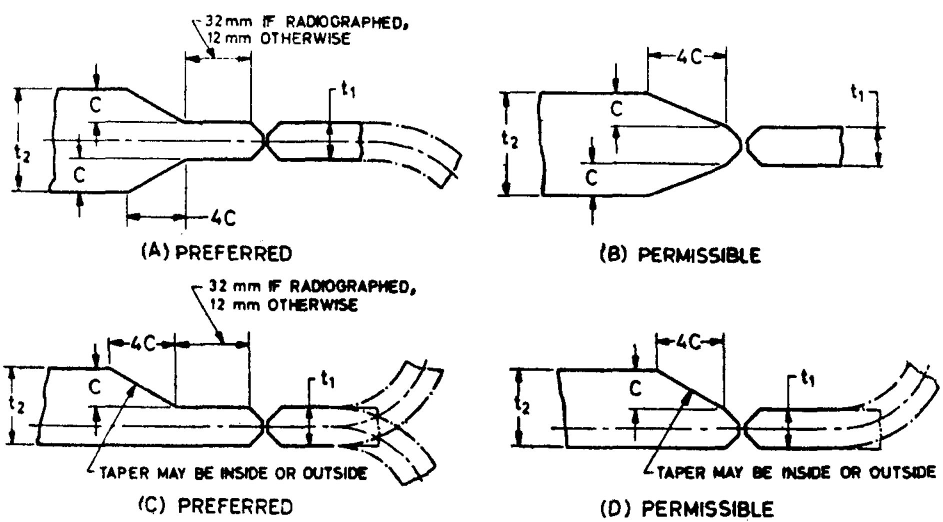


FIG. 6.1 BUTT WELDING PLATES OF UNEQUAL THICKNESS

from undercuts, overlaps or abrupt ridges or valleys.

6.3.6.2 Typical end connections to shells are given in Table 6.2.. Types of connections shown in Fig. 6.2 are not permissible.

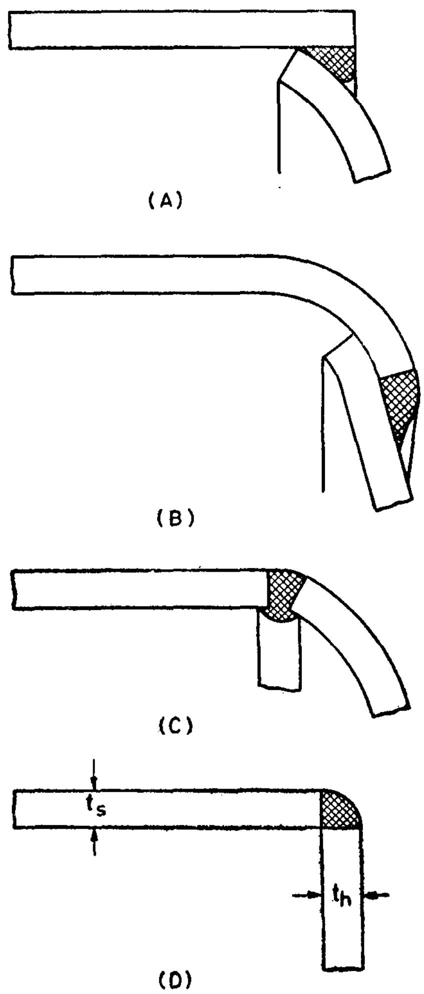


FIG. 6.2 PROHIBITED END CONNECTIONS

6.4 Preparation of Parent Metal

6.4.1 *Laying out and Cutting the Plate*

6.4.1.1 *Plate identification* — In laying out and cutting the plates, the manufacturer's brand shall be so located as to be clearly visible when the vessel is completed. Where the cast number, quality of plate, tensile strength and manufacturer's name or trade-mark are unavoidably cut out, they shall be transferred by the vessel manufacturers. The form of transferred markings shall be readily distinguishable from the plate manufacturer's stamping. The arrangement for the transferred markings should be agreed with the inspecting authority

6.4.1.2 *Cutting the plates* — Plate shall be cut to size and shape by machining and/or flame-cutting (*see* **6.4.2.2**). Where the plate thickness does not exceed 25 mm, cold shearing may be used provided that the sheared edge is cut back by machining or chipping for a distance of one-quarter of the plate thickness but in no case less than 3 mm.

6.4.2 *Preparation of Plate Edges and Openings*

6.4.2.1 Welding preparations and openings of the required shapes may be formed by the following methods:

a) Machining, chipping or grinding; chipped surfaces which are not covered with weld metal shall be ground smooth after chipping.

b) Flame-cutting (*see* **6.4.2.2**) which includes plasma arc, oxy-gas with or without flux injection or equivalent fusion cutting processes.

6.4.2.2 Carbon steel may be cut by any of the methods described in **6.4.2.1** but alloy steels and non-ferrous metals shall not be flame-cut unless otherwise agreed to between the purchaser and the manufacturer. Attention is drawn to the necessity of providing special inspection for cracks on the cut surfaces and heat affected zones in flame-cut alloy or high carbon steels; preheating may be required in order to ensure satisfactory results.

Any material damaged in the process of cutting plates to size or forming welding grooves shall be removed by machining, grinding or chipping back to sound metal. Surfaces which have been flame-cut shall be cut back by machining or grinding so as to remove all burnt metal, notches, slag and scale, but slight discolouration of machine flame-cut edges on mild steel shall not be regarded as detrimental. If alloy steels are prepared by flame-cutting, the surface shall be dressed back by grinding or machining for a distance of at least 1·5 mm unless it has been shown that the material has not been damaged by the cutting process.

6.4.2.3 After the edges of the plates have been prepared for welding they shall be given a thorough visual examination for flaws, cracks, laminations, slag inclusions or other defects. When plates are flame-cut, the edges should be examined after this operation.

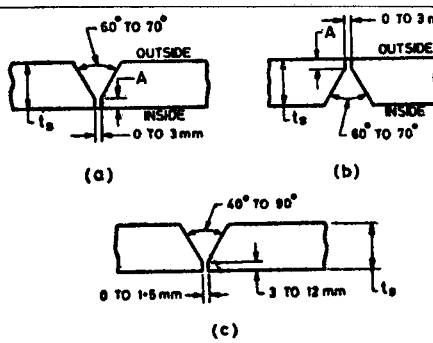
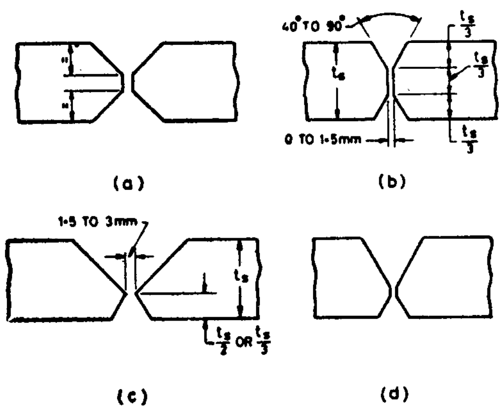
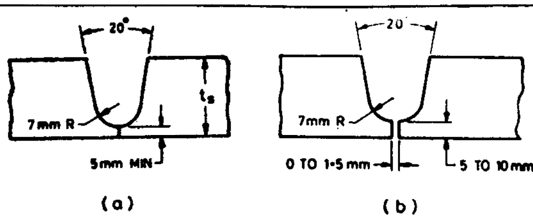
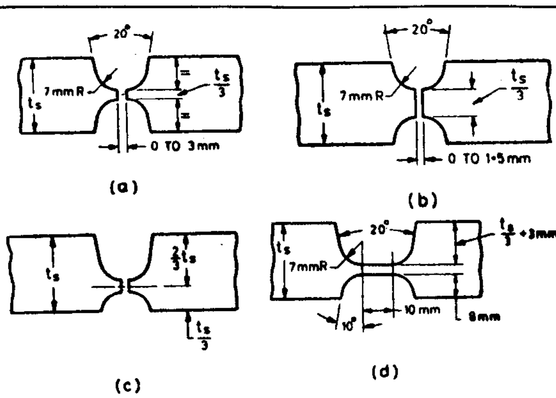
6.4.2.4 Care shall be taken to see that the weld preparations are correctly profiled.

6.4.2.5 Edges which have been flame-cut by hand shall be cut back by machining or chipping for a distance of one-quarter of the plate thickness, but in no case less than 3 mm.

6.4.3 Edge surface discolouration which may remain on flame-cut edges shall not be regarded as detrimental, but burnt metal, slag and scale shall be removed. Brushing of stainless steel edges shall be done with stainless steel brushes only.

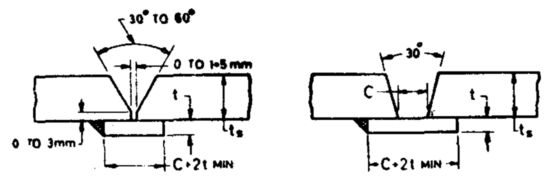
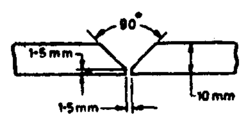
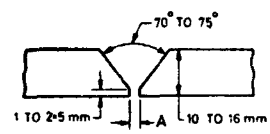
TABLE 6.1 SOME ACCEPTABLE TYPES OF BUTT WELDED JOINTS AND THEIR LIMITATIONS*

(*Clauses* 6.3.6 *and* 8.7.3.2)

SL No.	JOINT DETAIL	FIGURES	APPLICATION
i)	Double-welded butt joint with single 'V'		Longitudinal and circumferential butt welds in plates not less than 5 mm thick and not more than 20 mm thick. The 'V' should be on the inside of small diameter vessel, as shown in (b) opposite.
ii)	Double-welded butt joint with double 'V'		Longitudinal and circumferential butt welds where the thickness is greater than 20 mm. Each side welded in several layers.
iii)	Double-welded butt joint with single 'U'		Longitudinal and circumferential butt welds in plates where the thickness is greater than 20 mm. Welded in several layers.
iv)	Double-welded butt joint with double 'U'		Longitudinal and circumferential butt welds where the thickness is greater than 20 mm. Each side welded in several layers.

(*Continued*)

TABLE 6.1 SOME ACCEPTABLE TYPES OF BUTT WELDED JOINTS AND THEIR LIMITATIONS* — *Contd*

Sl No.	Joint Detail	Figures	Application
v)	Single-welded butt joint with backing strip	 (a) (b) $C \begin{cases} \text{8 mm UP TO 8 mm THICKNESS } (t_s) \\ \text{10 mm ABOVE 8 mm THICKNESS } (t_s) \end{cases}$	Welded with backing bar in several layers. Device essential to prevent slag or powder running through welding.
vi)	Single-welded butt joint with 'V' groove, without backing strip		Butt welds in plates not exceeding 10 mm thickness.
vii)	Single-welded butt joint with 'V' groove, without backing strip	 $A \begin{cases} \text{1·5 mm UP TO 10 mm THICKNESS} \\ \text{3·0 mm ABOVE 10 mm THICKNESS} \end{cases}$	Butt welds in plates having a thickness not more than 16 mm.

*The use of other types of joints that meet the requirements of this code are acceptable.

6.4.4 Rust, scale, painting, oil, slag, etc, from the flame-cutting or other contaminations of the fusion faces shall be removed before welding is commenced. In case of stainless steels this is usually achieved by degreasing or pickling or both (for details, *see* **8** of IS : 2811-1964*).

6.4.5 The surfaces to be welded shall be free from foreign material, such as grease, oil, or marking paints for a distance of at least 25 mm from the welding edges. Irregularities in fusion faces which are likely to affect the quality of welding shall be removed before welding is commenced.

6.4.6 Cast surfaces to be welded shall be machined, chipped or ground to remove foundry scale and to expose sound metal.

6.4.7 In the preparation of the fusion faces care shall be taken that surface irregularities are kept within such limits that they have no detrimental influence on the quality of the welded joint and that the profile prescribed is kept within the tolerances according to the best manufacturing practices.

6.4.8 All plate edges, after cutting and before carrying out further work upon them, shall be examined for laminations and also to make certain that cracks have not been caused by shearing.

6.4.9 Plates for shell sections and end plates shall be formed to the required shape by any process that does not impair the quality of the material. Carbon and low alloy steel plates may be formed by blows at a forging temperature provided the blows do not objectionably deform the plate and it is subsequently normalized or suitably heat-treated as may be agreed to between the manufacturer and the inspecting authority.

6.4.10 Cold-formed plate material shall not be subject to a deformation of more than 5 percent, unless suitable heat treatment is carried out after such forming. Heat treatment shall, however, be carried out even when the deformation is less than 5 percent, if there is a pronounced risk of brittleness through ageing. The deformation expressed as a percentage is obtained from the formula:

$$\text{Deformation} = \frac{t \times 100}{D}$$

where

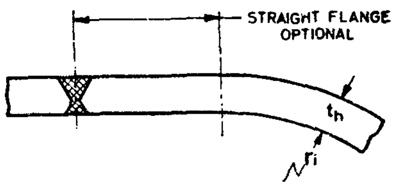
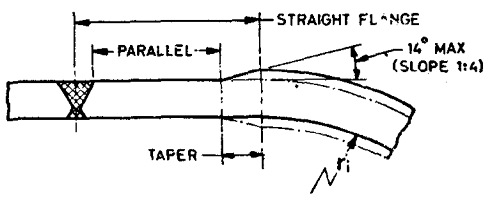
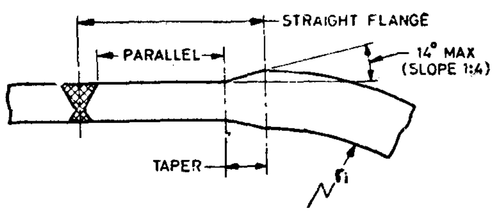
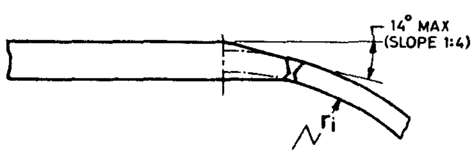
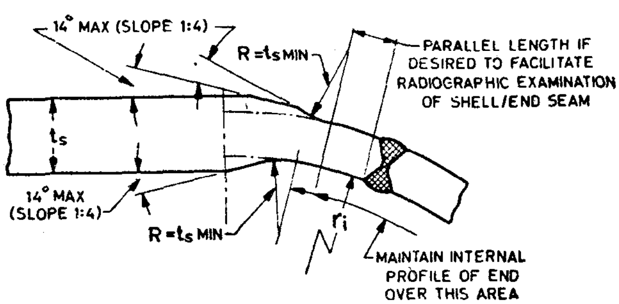
t = thickness of the plate, and

D = internal diameter to which the plate is bent or formed.

*Recommendations for manual tungsten inert-gas arc-welding of stainless steel.

TABLE 6.2 TYPICAL END CONNECTIONS TO SHELLS*

(*Clauses* 3.4.7, 6.3.2.1, 6.3.5 *and* 6.3.6.2)

SL No.	FIGURES	REMARKS
i)		
ii)		Offset may be internal or external. Taper may include weld, if desired.
iii)		Internal and external offsets need not be symmetrically disposed. Tapers may include weld, if desired.
iv)		Suitable for the connection of a hemispherical and thinner than the shell. *See* Table 6.1 for recommended weld preparation.
v)		Suitable for the connection between ends and shells.

*Dished ends of full hemispherical shape concave to pressure, intended for butt welded attachment, need not have an integral skirt, but where one is provided, the thickness of the skirt shall be at least that required for a seamless shell of the same diameter.

Cold-forming shall not be undertaken when the temperature of the metal is less than 0°C. If the forming or bending operation takes place in hot condition, no subsequent heat treatment is required, if the final shaping process terminates within the correct temperature limits for the particular material.

6.4.11 *Plates Welded Prior to Forming* — Seams in plates may be welded prior to forming provided they meet the specified mechanical test requirements and that they are examined radiographically throughout the entire length after forming. After forming, the surfaces of such seams in alloy steel parts, also in carbon steel parts over 25 mm in thickness, shall be ground smooth and inspected for cracks by magnetic crack detection, dye penetrants or other agreed means.

6.4.12 Cold-rolling of a welded shell to rectify a small departure from circularity is permitted, subject to the concurrence of the inspecting authority provided that the radiography (*see* **8.7**) takes place after such cold-rolling, where radiography is called for.

6.4.13 *Butt Welds Between Plates of Unequal Thickness* — Where two plates at a welded joint differ in thickness by more than 3 mm the thicker plate shall be trimmed to a smooth taper as stipulated in **6.3.5**.

6.5 Assembly of Plates and Fit-Up

6.5.1 Bars, jacks, clamps, tack welds or other appropriate means may be used to hold the edges to be welded in line. All tack welding shall be properly carried out in such a manner that no crack arises in tack welds or in parent metal. Tack welds shall be of sufficient length and size to avoid subsequent cracking. Tack welds in plates shall subsequently be removed so that they do not become part of the joint.

NOTE — Tack welds in plates below 7 mm thick need not be removed, if it can be demonstrated to the satisfaction of the inspecting authority, that they are of sufficient length and have proper penetration to form part of the subsequent weld.

6.5.2 When the plates are kept in position by tacking bars welded to the plates, such bars shall be properly removed, after the welding, in such a manner that no grooves or notches are left in the plate surface.

6.5.3 Where a root gap is specified, the edges of butt joint shall be held so that the correct gap is maintained during welding. The increase or decrease in root gap at any point in a seam, after tacking, shall not vary by more than 1·0 mm.

6.5.4 While making fillet welds, the mating surfaces should fit properly everywhere, so that the effective throat thickness of the weld shall be not less than those specified in the drawing.

6.5.5 Where fillet welds are used, the lapped plates shall fit closely and be kept together during welding. Domed ends which are inserted in the shell shall be a good fit.

6.5.6 The edges of butt joints shall be properly aligned so that the tolerances given in **6.6** are not exceeded in the completed joint. Where fitted girth joints have deviations exceeding the permissible tolerances, the head or shell ring whichever is not true shall be re-formed until the errors are within the limits specified.

6.6 Alignment and Tolerances

6.6.1 *General* — The shell sections of completed vessels shall be circular within the limits defined in **6.6.4** and **6.6.5**. Measurements shall be made to the surface of the parent metal and not to a weld, fitting or other raised part.

6.6.1.1 Shell sections may be measured for out-of-roundness either when laid flat on their sides or when set up on end. When the shell sections are checked whilst lying on their side, each measurement for diameter shall be repeated after turning the shell through 90° about its longitudinal axis. The two measurements for each diameter shall be averaged and the amount of out-of-roundness calculated from the average values so determined.

6.6.1.2 There shall be no flats or peaks at welded seams and any local departure from circularity shall be gradual.

6.6.2 Before any welding is commenced, it shall be ascertained that the chamfered edges are in alignment and that the defects in alignment at the surface of the plates are less than:

a) *For plates of thickness* 5 mm *or less* — $t/6$ for a longitudinal seam and $t/4$ for a circumferential seam subject to a maximum of 1 mm.

b) *For plates over 5 mm in thickness* — Before any welding is commenced it shall be ascertained that the prepared edges are in alignment to meet the requirements of the welding process and that the defects in alignment at the surface of the plates are not more than:

   1) 10 percent of the nominal plate thickness with a maximum of 3 mm for longitudinal joint. However, for plates up to and including 10 mm thick a misalignment of 1 mm is permitted.

   2) 10 percent of the maximum nominal plate thickness plus 1 mm with a maximum of 4 mm for circumferential joints.

NOTE — Welds made with backing strips require better alignment than specified above.

6.6.3 *Circumference* — Unless otherwise agreed upon, the external circumference of the completed shell shall not depart from the calculated circumference based upon nominal inside diameter and

the actual plate thickness by more than the following amounts:

Outside Diameter (Nominal Inside Diameter Plus Twice Actual Plate Thickness)	*Circumferential Tolerance*
300 mm up to and including 600 mm	± 5 mm
Over 600 mm	$\pm 0{\cdot}25$ percent

Notwithstanding the requirements of this clause, the misalignment tolerances for two mating parts given in **6.6.2** shall be the governing factor.

6.6.4 *Out of Roundness of Vessels* — The difference between the maximum and minimum diameter at any cross section of a drum or shell welded longitudinally shall not exceed 1 percent of the nominal internal diameter with a maximum of

$$\frac{D_i + 1\,250}{200}.$$

6.6.4.1 At nozzle positions a greater out of roundness may be permitted if it can be justified by calculation and is agreed between the purchaser, manufacturer and the inspecting authority.

6.6.4.2 To determine the difference in diameters, measurements may be made on the inside or the outside of the drum or shell. If the drum or shell is made of plates of an unequal thickness, the measurements shall be corrected for the plate thicknesses as they may apply to determine the diameter at the middle line of the plates. The skirts of heads shall be sufficiently round, so that the difference between the maximum and the minimum diameters shall not exceed 1 percent of the nominal diameter.

6.6.4.3 For vessels with longitudinal lap joints, the permissible difference in inside diameters may be increased by the nominal plate thickness.

6.6.5 Irregularities in profile (checked by a 20° gauge) shall not exceed 3 mm plus 5 percent of the minimum plate thickness. The maximum value may be increased by 25 percent if the length of the irregularity does not exceed one-quarter of the length of the shell ring with a maximum of 1 000 mm.

6.6.5.1 There shall be no flats at welded seams and any local departure from circular forms shall be gradual. Cold rolling of a welded shell to rectify a small departure from circularity is permitted, but if this occurs it must be done before the non-destructive examination of the seams as specified in **8.7**.

6.6.6 The individual cylindrical shells shall be reasonably square and straight. Unless otherwise specified the out of straightness of the shell shall not exceed 0·3 percent both of the total cylindrical length any 5 m length. (This tolerance may be omitted where the individual shell length does not exceed 2 m.)

6.6.7 *Tolerance on Formed Heads* — The inner surface of a head shall not deviate from the specified shape by more than 1·25 percent of the inside diameter of the head skirt. Such deviations shall not be abrupt, shall be outside of the theoretical shape, and shall be measured perpendicular to the specified shape.

6.6.7.1 The skirts of heads shall be sufficiently true to round so that the difference between the maximum and minimum diameters shall be within the limits specified in **6.6.4**.

6.6.7.2 When the skirt of any unstayed formed head is machined to make a close and accurate fit into or over a shell, the thickness shall not be reduced to less than 90 percent of that required for blank head. When so machined, the transition from the machined thickness to the original thickness of the head shall not be abrupt but shall be tapered for a distance of at least four times the difference between the thicknesses.

6.6.7.3 *Vessels fabricated from pipe* — The permissible variation in outside diameter of vessels fabricated from pipe shall be in accordance with the requirements of the specification governing the manufacture of pipe.

6.6.8 *Attachments and Fittings* — All lugs, brackets, saddle-type nozzles, manhole frames, reinforcement around openings, and other attachments shall conform reasonably to the curvature of the shell or surface to which they are attached.

6.7 Welding Procedure

6.7.1 All welding shall be carried out using a suitable welding sequence and in such a manner that harmful secondary effects are avoided. Wherever possible welding should be carried out in downhand position.

6.7.2 During the execution of welding the working side shall be suitably sheltered against the influence of weather (wind, rain and snow). No welding of any kind shall be done when the temperature of the base metal is lower than 0°C in the vicinity of the welds. When the base metal temperature is below 0°C, the surfaces of all areas within 200 mm of the joint, where a weld is to be deposited, should be heated to a temperature at least warm to the hand (15°-20°C). The arc shall not be struck on those parts of the parent metal where weld metal is not to be deposited (*see also* IS : 4944 - 1968*).

6.7.3 If preheating is required, it shall be carried out properly keeping strictly the temperature needed over a sufficient width of the base material on both sides of the welded joint.

6.7.4 Fusion faces should be as even as possible throughout and the weld grooves be of uniform width. In the preparation and execution of

*Code of procedure for welding at low ambient temperatures.

work, complete fusion without lack of penetration at the root of the joint shall be ensured.

6.7.5 Each run of weld metal shall be thoroughly cleaned and all slag removed before the next run is deposited.

6.7.6 The use of a filler material that will deposit weld metal with a composition and structure as near as that of the material being welded is recommended.

6.7.7 In making fillet welds, the weld metal shall be deposited in such a way that adequate penetration into the base metal at the root of the weld is ensured.

6.7.8 In fillet welding the lapped plates shall fit closely and melting of the sharp edges shall be avoided (*see* Fig. 6.3).

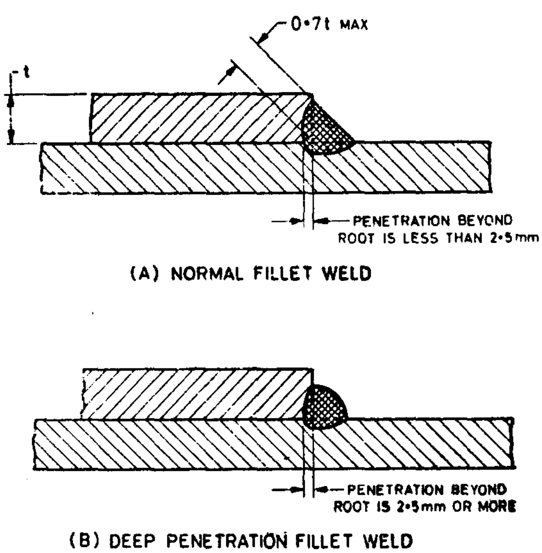


Fig. 6.3 Types of Fillet Welds

6.7.9 Double butt welded joints shall be welded from both sides of the plate. Before the second side of the plate is welded, the metal at the bottom of the first side shall be removed to sound metal by grinding, chipping, machining or other approved methods.

6.7.10 The requirements of **6.7.9** are not necessary if the welding process employed ensures complete fusion otherwise and the base of the weld remains free from impurities.

6.7.11 After welding has been stopped for any reason, care shall be taken in restarting to ensure proper fusion and penetration between the plates, the weld metal and the previously deposited weld metal, which shall be thoroughly cleaned and freed from slag.

6.7.12 When butt joints are to be welded from one side only, care shall be taken in aligning and separating the edges to be joined, in order to ensure proper fusion and penetration at the bottom of the joint.

6.7.13 When butt joints are to be welded from one side only, the root side of the joints shall be subjected to close inspection, whereby a distinction is made between the irregularities and defects as shown in Fig. 6.4.

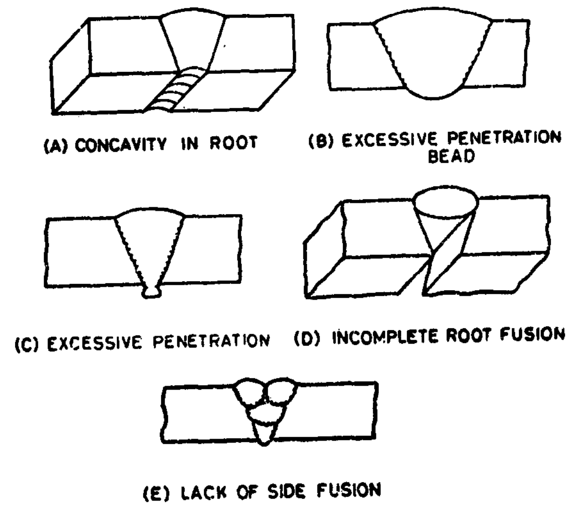


Fig. 6.4 Weld Defects

6.7.13.1 Irregularities of the types (A), (B) and (C) shown in Fig. 6.4 may be accepted subject to approval of the inspecting authority. Defects of the types (D) and (E) (unfused corners in the root) are not permitted.

6.7.14 Plug or slot welds shall be formed by depositing a fillet around the inside edge of the hole and leaving the centre open for inspection. The hole or slot shall not be filled flush with weld metal except where this is required to complete a corrosion-resistant surface.

6.7.15 The surface of the welds shall be smooth and have gentle transition to the plate surface. The weld metal shall fill the groove completely forming a smooth connection with the parent metal on both sides and shall be free from pronounced surface irregularities, such as undercuts, cracks, overlaps, abrupt ridges or valleys, or irregular beads.

6.7.16 Additional weld metal may be deposited as reinforcement on each side of the plate so as to ensure that the weld grooves are completely filled and the surface of the weld metal at any point does not fall below the surface of the adjoining plate. The thickness of the reinforcement on each side of the plate shall not exceed the following thickness in case of severe and medium duty vessels:

Plate Thickness mm	*Thickness of Reinforcement, Max* mm
Up to 12	1·5
Over 12 up to and including 25	2·5
Over 25 up to and including 52	3·0
Over 52	4·0

In case of light duty vessels, the reinforcement shall be not more than 5 mm.

6.7.17 The reinforcement need not be removed except when it exceeds permissible thickness or when required under **8.7**.

6.7.18 Cracks, lack of fusion, undercutting, incomplete root fusion, porosity or slag inclusions, which affect the strength of welded joints shall not be permitted beyond the limits permitted in **8.7.5.3** and **8.7.5.4**.

6.7.19 If backing strip is used, it shall be of such material that it does not influence the weld adversely. Wherever possible the backing strip shall be removed after welding but prior to carrying out the required non-destructive tests (*see* **8.7**).

6.7.20 If backing rings or consumable insert backing rings are used for pipes and tubes, these shall be of such material and design and be so fitted that their use does not cause defect in the weld. If non-consumable backing rings are left in place these shall be properly secured and when necessary they shall have a contour on the inside to minimize the restriction to flow and permit the passage of a tube cleaner.

6.7.21 If the pipe or tube wall is recessed for a backing ring, the depth of such recess shall be so limited that the remaining net section of the wall shall be at least equal to that required for the pipe or tube. A diminution of thickness of not more than 0·8 mm is allowable if compensation is made for it by an equivalent increase in the reinforcement of the weld.

6.7.22 Not less than two runs of weld metal shall be deposited at each weld affixing branch pipes, flanges and seatings.

6.7.23 It is recommended that while finishing or dressing welds it shall be ensured that unavoidable scratches arising in the finishing or dressing process run parallel with the direction of greatest tensile stress in the weld due to the internal or external pressure or form an angle not exceeding 45°. While chipping and grinding care is to be taken that cracks, local indentations or hardening effects do not arise.

6.7.24 Circumferential joints of headers, pipes and tubes of small diameters are permitted to be welded from one side only, with or without backing strips. The design of the joint and the method of welding shall provide full penetration and it shall be demonstrated by a qualification test and/or radiography that the welding method produced a weld that is free from significant defects.

6.7.25 All persons engaged in welding of pressure vessels shall be adequately protected and the safety requirements stipulated in IS : 818-1957* and IS : 3016-1965† shall be complied with.

*Code of practice for safety and health requirements in electric and gas welding and cutting operations.

†Code of practice for fire precautions in welding and cutting operations.

6.7.26 Arc flashes should be ground out and welds used for the attachment of erection cleats should be ground flush with the plate surface.

6.7.27 In case of vessels required to operate at low temperatures the ends of branch pipes and other openings in the vessels shall be ground to a smooth radius after all welding is complete.

6.7.28 The method of welding steel clad with the corrosion-resistant linings is given in Appendix J for information.

6.8 Welding of Non-ferrous Metals

6.8.1 *Gas Welding* — The commonly used gas processes for welding aluminium-base materials employ oxy-hydrogen or oxy-acetylene flames whereas only the latter produces sufficient heat for welding the copper-base and nickel-base alloys. For the aluminium-nickel and cupro-nickel alloys a neutral to slightly reducing flame should be used, whereas for copper-base materials the flame should be neutral to slightly oxidizing. A suitable flux, applied to the welding rod and the work, shall be used except that no flux is required for nickel. Boron-free and phosphorus-free fluxes are required for nickel-copper alloys and for nickel-chromium-iron alloys. Residual deposits of flux shall be removed.

6.8.2 *Metal-Arc Welding* — Metal-arc welds may be made with standard dc equipment using reversed polarity (electrode-positive) and covered electrodes. A slightly greater included angle in butt welds for adequate manipulation of the electrode is required.

6.8.3 *Inert-Gas Metal-Arc Welding* — Both the consumable and non-consumable electrode processes are particularly advantageous for use with the non-ferrous materials. Best results are obtained through the use of special filler metals (*see also* IS : 2812-1964* and IS : 2680-1964†).

6.8.4 *Resistance Welding* — Electric resistance welding, which includes spot, line or seam, and butt or flash welding, may be used with the non-ferrous materials. Proper equipment and technique are required for making satisfactory welds.

6.9 Rectification of Welds

6.9.1 Visible defects, such as cracks, pinholes and incomplete fusion and defects detected by the pressure test or by the examinations prescribed in **8.7.1**, **8.7.2** and **8.7.11**, shall be repaired by removing the defective material by grinding, chipping, machining, flame gouging or other approved methods to sound metal, and re-welding, care being taken to ensure proper penetration and complete fusion of the fresh weld deposit with the plates and previously deposited weld metal.

NOTE — The welding procedure for repairing the cracks suggested here is non-mandatory and is subjected

*Recommendations for manual tungsten inert-gas arc-welding of aluminium and aluminium alloys.

†Filler rods and wires for inert gas tungsten arc welding.

to the approval of the inspecting authority. A hole of about 10 mm diameter, depending on the plate thickness is drilled and countersunk at each end. The edge of the hole shall be about 50 mm away from either end of the crack. The distance between the holes shall be opened out by a V- or U-groove to the required depth and rewelded. The holes shall be filled last. It shall be ensured by radiographic examination that no further crack has developed and the portion thus repaired meets the requirement of this code.

6.9.1.1 Repairs to welded joint cracks and to minor plate defects may be made after chipping out a U- or V-groove to full depth and length of the crack and filling this groove with weld metal deposited in accordance with **6.7**.

6.9.2 When repeated repairs are to be carried out on the same part of a welded joint, adequate precautions shall be taken to avoid a detrimental accumulation of residual stresses.

6.9.3 If the defects form a continuous line, the extent of repair shall be agreed upon between the manufacturer and the inspecting authority.

6.9.4 All repairs carried out by the manufacturer on a finished vessel shall be reported to the inspecting authority. On completion of welded repairs, the manufacturer shall, if requested, supply for record purpose report of all repairs. No repair shall be carried out without prior approval of the inspecting authority.

6.9.4.1 When repairs are carried out because of defects found by a radiographic examination, all the radiographs causing the demand for repair shall be kept on record and placed before the inspecting authority upon request.

6.10 Repair of Drilled Holes — Holes drilled through the vessel wall for measuring thickness should be closed by welding with penetration for the full depth of the hole. Alternatively, these holes may be treated as unreinforced openings and closed by any method permitted under the rules specified in this code.

6.11 Repair of Cracks — Cracks or grooving in plates on which forming operations have been carried out may be removed to sound metal and welded subject to prior agreement between the purchaser and the inspecting authority.

6.12 Post Weld Heat Treatment

6.12.1 Post weld heat treatment shall be carried out as the last operation prior to the pressure test in the case of carbon and low alloy ferritic steels either by normalizing or by stress-relieving. Special heat treatment in the case of high alloy steels and in the case of non-ferrous metals where necessary shall be subject to agreement between the manufacturer and the inspecting authority.

6.12.2 Vessels or parts of vessels fabricated from carbon and low alloy steels shall be thermally stress-relieved by one of the procedures given in **6.12.3** when:

a) intended for containing toxic or inflammable material;
b) intended for operation below 0°C;
c) intended for use with media liable to cause stress corrosion cracking;
d) subjected to excessive local stress concentration which may give rise to cracking or subjected to changing loads and subsequent risk of fatigue failures;
e) risk of brittle fracture due to the combined influence of material, transition temperature, notch effect, etc;
f) it is necessary to maintain dimensional accuracy and shape in service; and
g) the plate thickness including corrosion allowance, at any welded joint in the vessel shell or head, exceeds the values given in Table 6.3 for various groups of materials.

6.12.2.1 When the welded joint connects plates that are of different thickness the plate thickness to be used in applying the requirements of stress-relieving in **6.12.2** (g) shall be the following:

a) The thinner of two adjacent butt welded plates including head to shell connections;
b) The thicker of the shell or head plate, in connections to intermediate heads;
c) The thickness of the shell in connections to tube sheets or similar constructions; and
d) The thickness of the shell or head plate in nozzle attachment welds.

6.12.2.2 All welding of connections and attachments shall be stress-relieved when the vessel or part thereof is required to be stress-relieved (*see* Table 6.3).

6.12.2.3 Heat treatment should be carried out after all welded connections have been attached to the vessel. When welding repairs have been done to a vessel which has been earlier heat-treated, the vessel shall be heat-treated again, unless such rectifications are of very minor nature.

6.12.2.4 Stress-relieving, when required, shall be done before the hydrostatic test and after any repairs to welding. A preliminary hydrostatic test at a pressure not exceeding 0·5 times the design pressure to reveal leaks prior to the stress-relieving operation is permissible.

6.12.2.5 Normalizing is desirable when a structural improvement is necessary as with pressure vessels that are subjected to blows and knocks. When welding pressure vessels that are to be normalized, the filler metal used shall be of the type, that the weld deposit will, after normalizing, meet the same requirements regarding the yield point as the parent metal. Considerations should be given to the deformations or stresses

TABLE 6.3 MAXIMUM PLATE THICKNESS ABOVE WHICH POST WELD HEAT TREATMENT IS REQUIRED

[*Clauses* 6.12.2 (g) *and* 6.12.2.2]

Material Group	Percentage Chemical Composition and Mechanical Properties	Plate Thickness
(1)	(2)	(3)
0	Carbon 0·20 *Max* Manganese 1·00 *Max* Residual elements 0·80 *Max* Specified minimum yield strength 26 kgf/mm² *Max*	30 mm (*see* Notes 2 and 3) However for fine grained steels (*see* Note 1) this may be increased to 38 mm when agreed to between purchaser, manufacturer and inspecting authority subject to preheating for thicknesses over 30 mm
1a	Carbon 0·25 *Max* Manganese 1·60 *Max* Residual elements 0·80 *Max* Specified minimum yield strength 38 kgf/mm² *Max*	
1b	Carbon 0·30 *Max* Manganese 1·20 *Max* Residual element 0·40 *Max* Specified minimum yield strength 38 kgf/mm² *Max*	
2a	Carbon 0·25 *Max* Manganese 1·60 *Max* Chromium 0·60 *Max* Molybdenum 0·60 *Max* Vanadium 0·12 *Max* Residual or other elements 0·80 *Max* Specified minimum yield strength 44 kgf/mm² *Max*	20 mm (*see* Notes 2 and 3)
2b	Carbon 0·35 *Max* Manganese 1·20 *Max* Residual or other elements 0·40 *Max* Specified minimum yield strength 44 kgf/mm² *Max*	
3	Carbon 0·25 *Max* Manganese 1·60 *Max* Chromium 1·50 *Max* Molybdenum 1·50 *Max* Vanadium 0·16 *Max* Residual or other element 0·80 Specified minimum yield strength 44 kgf/mm² *Max*	All thicknesses
4	All other ferritic steels	All thicknesses (*see* Note 4)

Note 1 — Fine grained steels are here considered to be those having Charpy V impact test value* of 3·5 kgf·m/cm² or 2·8 kgf·m at −20°C (longitudinal direction) which have been proved by impact tests.

Note 2 — For vessels of thickness over 15 mm and of steel which is not fine grained and where post-weld heat treatment is not carried out, the steels shall be Charpy V impact tested at 0°C and have an impact value* of 3·5 kgf·m/cm² or 2·8 kgf·m (longitudinal direction).

Note 3 — All vessels with a wall thickness over 5 mm, designed for service below −20°C shall be post-weld heat-treated.

Note 4 — For circumferential butt weld in pipes or tubes and for fillet welds attached with throat thicknesses not exceeding 8 mm, post-weld heat treatment is not mandatory under the following conditions:

a) Maximum specified chromium content of 3 percent
   " " carbon " " 0·15 percent
b) Maximum outside diameter 102 mm
c) Maximum thickness 8 mm
d) Minimum preheat temperature 150°C
e) Service temperature 450°C

**See* IS . 1757-1961 ' Method for beam impact test (V-notch) for steel '.

arising with the heating and cooling associated with the normalizing process.

6.12.2.6 A normalizing heat treatment before or after welding is required for hot-formed parts unless the process of hot-forming was carried out within a temperature range corresponding to normalizing.

6.12.3 *Procedure for Thermal Stress Relief* — The operation of thermal stress-relieving shall be performed in accordance with the requirements given in **6.12.2** using one of the following procedures.

6.12.3.1 The vessel shall be stress-relieved by heating as a whole in an enclosed furnace wherever practicable. Where it is not practicable to stress-relieve the entire vessel in one operation, the following procedures may be adopted. It may, however, be noted that these procedures may not ensure the same degree of immunity from susceptibility to stress corrosion cracking:

a) The vessel is heated in sections in an enclosed furnace, the minimum overlap of the heated sections being 1·5 m. Where this method is adopted, the vessel portion projecting outside the furnace shall be suitably shielded so that the temperature gradient is not harmful.

b) Circumferential seams in shells, piping and other tubular products may be locally stress-relieved by heating uniformly a shielded circumferential band around the entire circumference. The width of the heated band shall be not less than $5\sqrt{rt}$, where r and t are the radius and the thickness of the part stress-relieved, the weld being in the centre of the band. Sufficient insulation shall be provided to ensure that the temperature of the weld and heat affected zone is not less than that specified and the temperature at the edge of the heated band is not less than half the peak temperature. In addition the adjacent portion of the material outside the heated zone shall be protected by means of thermal insulation so that the temperature gradient is not harmful. A minimum width of insulation of $10\sqrt{rt}$ is recommended for the purpose of meeting these requirements.

c) **The vessel may also be heated internally for heat treatment, in which case the vessel shall be fully encased with insulating material. The internal pressure should be kept as low as possible and should not be such as to cause appreciable deformation at the highest metal temperature expected during heat treatment.**

d) **Shell sections or any other portion of a vessel may be heated to stress-relieve longitudinal joints or complicated welded details before being joined to make the completed vessel. When it is not practicable to stress-relieve the completed vessel as a whole or** in two or more parts as provided, any circumferential joint not previously stress-relieved may be thereafter locally stress-relieved after welding the closing joints, by heating such joints by any appropriate means that will assure the required uniformity. The width of the heated band shall be not less than $2{\cdot}5\sqrt{rt}$. The portion outside the heating device shall be protected so that the temperature gradient is not harmful. This procedure may also be used to stress-relieve portions of new vessels after repairs.

e) Branches, nozzles or other welded attachments may be locally stress-relieved by heating a shielded circumferential band. The band shall be heated up uniformly to the required temperature and held for the specified time. The circumferential band shall extend around the entire vessel, shall include the nozzle or welded attachment, and shall extend at least $2{\cdot}5\sqrt{rt}$ beyond the welding which connects the nozzle or other attachment to the vessel. The portion of the vessel outside of the circumferential band shall be protected so that the temperature gradient is not harmful. A minimum width of insulation of $2{\cdot}5\sqrt{rt}$ on either side of the heated band is recommended.

6.12.3.2 Where a welded production test plate is required, it shall be placed inside the drum during heat treatment, or where this is impracticable, the test plate may be placed alongside the drum in the furnace in such a position that it will receive similar heat treatment.

The test plate may be heat-treated separately from the drum provided that means are adopted to ensure that the conditions are the same for the test plate as for the drum, namely, rate of heating, maximum temperature, soaking temperature, soaking time, and rate of cooling.

6.12.4 Stress-relieving of welded pressure parts shall be effected by any of the following methods.

6.12.4.1 The temperature to which the material shall be heated for stress-relieving purposes shall be within 580° to 620°C with the following requirements:

a) The temperature of the furnace at the time the vessel is placed in it shall not exceed 300°C.

b) The rate of heating above 300°C shall not exceed 220 deg per hour up to and including 25 mm shell or end plate thickness. For shell or end plate thickness over 25 mm the rate of heating above 300°C shall be $\dfrac{5\ 500}{\textit{Max}\ \text{shell or end plate thickness in mm}}$ deg per hour or 55 deg per hour, whichever is greater.

c) During the heating period there shall not be a greater variation in temperature throughout the portion of the vessel being

heated than 150 deg within any 4·5 m interval of length, and when at the holding temperature, the temperature not more than 50 deg throughout the portion of the vessel being heated shall be within the range 580° to 620°C.

d) When it is impracticable to stress-relieve at a temperature of 580° to 620°C, it is permissible to carry out the stress-relieving operation at lower temperatures for longer periods of time in accordance with the following:

Metal Temperature °C	*Time of Heating, Minutes/mm of thickness*
575	3·5
550	6·0
525	9·0

For intermediate temperatures, the time of heating shall be determined by straight line interpolation.

6.12.4.2 When the vessel has attained a uniform temperature as specified above, the temperature shall be held constant for a period of 2·5 minutes or longer as may be necessary per millimetre of the maximum thickness of the shell or end plate subject to a minimum of one hour.

6.12.4.3 During the heating and holding period the furnace atmosphere shall be so controlled as to avoid excessive oxidation of the surface of the vessel. There shall be no direct impingement of the flame on the vessel.

6.12.4.4 The vessel shall be cooled in the furnace to 400°C at a rate not exceeding:

Up to and including 25 mm *Max* thickness of shell or end plate	275 deg per hour
Over 25 mm *Max* thickness of shell or end plate	$\frac{7\,000}{\textit{Max}\text{ shell or end plate thickness in mm}}$ deg per hour or 55 deg per hour whichever is greater

Below 400°C the vessel may be cooled in still air.

6.12.4.5 The temperatures specified shall be the actual temperatures of any part of the vessel and shall be determined by thermocouples in contacts with the vessel.

All temperatures shall be recorded continuously and automatically.

6.12.4.6 A temperature-time diagram of the stress-relieving operation shall be provided with all the vessels requiring stress relief according to this code.

6.12.4.7 The minimum temperature for stress relief given above shall be the minimum temperature of the plate material of the shell or head of any vessel. Where more than one pressure vessel or pressure vessel part is stress-relieved in one furnace charge, thermocouples shall be placed on vessels at the bottom, centre, and top of the charge, or in other zones of possible temperature variation so that the temperature indicated shall be the true temperature for all vessels or parts in those zones*.

6.12.5 *Alloy Steels* — The most suitable post-weld heat treatment temperature and thermal cycle depends upon the composition of the alloy and any special properties which may be required. When such materials are to be heat-treated, these details shall be given special consideration and shall be agreed to between the purchaser (or inspecting authority) and the manufacturer.

Table 6.4 is given as a guide for heat treatment and the effect of the heat treatment proposed should be considered in regard to any special requirements.

TABLE 6.4 HEAT TREATMENT FOR ALLOY STEELS

Type of Steel	Range of Temperature	Time in Minutes per mm of Thickness
C-½ Mo ½ Cr-½ Mo	620-660°C	2·5 (1 hour *Min*)
1 Cr-½ Mo 1¼ Cr-½ Mo	620-660°C	2·5 (1 hour *Min*)
2¼ Cr-1 Mo*	600-750°C	2·5 (2 hours *Min*)
5 Cr-½ Mo	700-740°C	2·5 (2 hours *Min*)
3½ Ni	580-620°C	2·5 (1 hour *Min*)

*This wide range for the post-weld heat treatment temperature is necessary because of the marked dependence of the mechanical properties of this steel on the tempering temperature.

In production a definite temperature with a tolerance of ±20°C would be selected to ensure that the mechanical properties upon which the design was based are in fact achieved.

6.12.6 *Other Heat Treatments*

6.12.6.1 If a normalizing heat treatment has to be carried out, the part to be normalized shall be brought up to the required temperature slowly and held at that temperature for a period sufficient to soak the part thoroughly. If the geometry of the part causes insufficiently homogeneous cooling, a stress-relieving heat treatment shall be applied after the normalizing heat treatment.

6.12.6.2 Other heat treatments (tempering, quenching and tempering, etc) have to be carried out in conformity with the procedure agreed by the manufacturer, purchaser and inspecting authority, according to the type, grade and thickness of the steel.

*Furnace gas temperature measurement alone is not considered sufficiently accurate.

7. WELDING QUALIFICATIONS

7.1 Welding Procedure Qualifications

7.1.1 When a manufacturing firm furnishes proof, satisfactory to the customer in conjunction with his inspecting authority, that it has previously made successful procedure qualification tests or successfully undertaken the manufacture of boiler components, in respect of method, base and filler metal or thickness within a period of 3 years, in accordance with the requirements of an approved standard, such a firm shall be deemed exempt from the necessity of requalifying under the requirements of this code within the range covered by the previous tests. When the manufacturer commences any welding not previously qualified and successfully undertaken by him as regards methods, parent metal, filler material, thickness and equipment, he shall prove to the inspecting authority that his organization is capable of welding the materials to be used. For this purpose, test welds shall be made in accordance with the limitations stated in the following clauses.

7.1.2 All test welds for welding procedure qualifications shall be carried out as butt welds. If the production welding is to be done in the downhand position, the procedure test plate shall also be welded in the downhand position. If the production welding is done in any other position, the procedure test weld shall be welded in a similar position. Similar positions are regarded as positions falling within the limits of any fundamental welding position given in IS : 815-1966*.

7.1.2.1 *Test positions for butt welds* — Butt welds for making tests for procedure qualification and welder's performance qualification shall be made in the following basic positions:

a) *Downhand position* — Plate and pipe in a horizontal plane with the weld metal deposited from above (*see* Fig. 7.1 A-1 and 7.1 A-2).

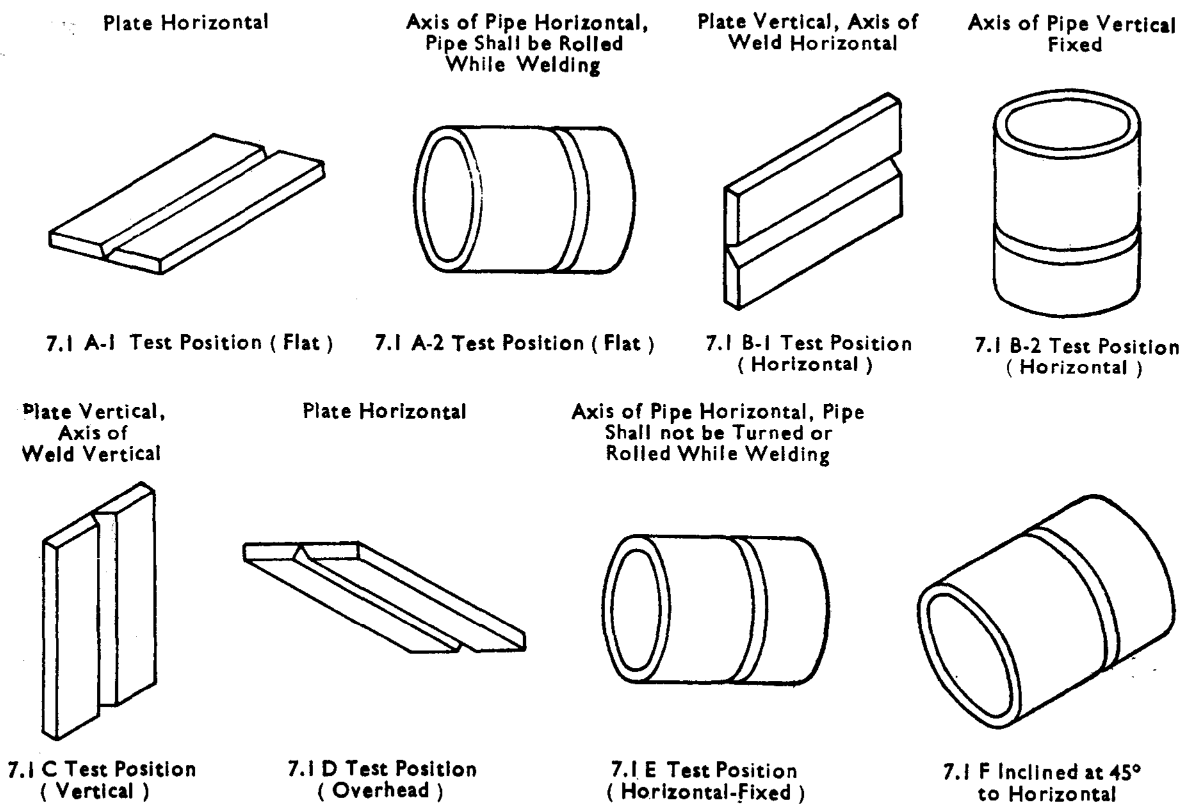
b) *Horizontal position* — Plate and pipe in a vertical plane with the axis of the weld horizontal. Welding shall be done without rotating the pipe (*see* Fig. 7.1 B-1 and 7.1 B-2)

c) *Vertical position* — Plate in a vertical plane with the axis of the weld vertical (*see* Fig. 7.1C)

d) *Overhead position* — Plate in a horizontal plane with the weld metal deposited from underneath (*see* Fig. 7.1D)

e) *Horizontal fixed position* — Pipe with its axis horizontal and with the welding groove in a vertical plane. Welding shall be done without rotating the pipe so that weld metal is deposited from the flat, vertical, and overhead positions (*see* Fig. 7.1E)

*Classification and coding of covered electrodes for metal arc welding of mild steel and low alloy high tensile steels (*revised*).



7.1 A-1 Test Position (Flat) — 7.1 A-2 Test Position (Flat) — 7.1 B-1 Test Position (Horizontal) — 7.1 B-2 Test Position (Horizontal)

7.1 C Test Position (Vertical) — 7.1 D Test Position (Overhead) — 7.1 E Test Position (Horizontal-Fixed) — 7.1 F Inclined at 45° to Horizontal

FIG. 7.1 POSITIONS OF TEST PLATES OR PIPES FOR WELDER QUALIFICATION AND PERFORMANCE OF BUTT WELDS

An additional test position in case of butt welded pipes is the pipe inclined at 45°C to the horizontal (*see* Fig. 7.1F).

7.1.2.2 Qualification in the horizontal, vertical, or overhead position shall qualify also for the downhand position. Qualification in the horizontal fixed position, shall qualify for the downhand, vertical, and overhead positions. For pipes qualification in the horizontal, vertical and overhead positions shall qualify for all positions.

7.1.3 Apart from what is specified in **7.1.1** and **7.1.2**, procedure qualification test welds for all pressure parts of pressure vessels shall be made in such a manner that the welds are considered representative of those made in production, taking into account the following essential variables.

7.1.3.1 *Type of parent metal*

a) *Steel* — The procedure qualification test plates or test pipes shall be made from steel with a tensile strength in the same range as that of the steel to be used in the construction and a chemical composition approximately corresponding to the most unfavourable analysis from the standpoint of weldability and within the limits of the material specification of the steel concerned. A procedure qualification made on steel with a certain tensile strength and a certain chemical analysis shall also cover the use of steels having a lower strength and a more favourable chemical analysis. In the case of plain carbon or carbon-manganese or alloy steels, these requirements are considered to be met, as long as the steel used for production and for the procedure qualification, both fall within the limits of one of the following groups:

i) *Low alloy and carbon steels*

1. Grade St 42 IS : 226-1962 Specification for structural steel (standard quality) (*third revision*)
2. Grade St 55-HTW IS : 961-1962 Specification for structural steel (high tensile) (*first revision*)
3. Grade St 42 W IS : 2062-1962 Specification for structural steel (fusion welding quality)
4. Grade C15Mn75 IS : 1570-1961 Schedules for wrought steels for general engineering purposes
5. IS : 2041-1962 Specification for steel plates for pressure vessels
6. Grade 20Mo55 IS : 1570-1961 Schedules for wrought steels for general engineering purposes
7. IS : 2002-1962 Specification for steel plates for boilers
8. Grades 1 and 2 of IS : 3038-1965 Specification for alloy steel castings for pressure containing parts suitable for high temperature service (fusion welding quality)
9. IS : 1914-1961 Specification for carbon steel boiler tubes and superheater tubes
10. IS : 2416-1963 Specification for boiler and superheater tubes for marine and naval purposes
11. IS : 2004-1962 Specification for carbon steel forgings for general engineering purposes
12. IS : 3039-1965 Specification for structural steel (shipbuilding quality)
13. IS : 3503-1966 Specification for steel for marine boilers marine pressure vessels and welded machinery structures
14. IS : 3945-1966 Specification for steel for naval purposes
15. Carbon and carbon-manganese steels conforming to material group 0 and 1 of Table 6.3 except those used for low temperature operation.

NOTE — Carbon over 0·23 percent is subject to agreement between the manufacturer and the inspecting authority. In these cases preheating is recommended.

ii) *Alloy steels (other than high alloy heat resisting and stainless steels)*

1. Alloy steels conforming to material group 2, 3 and 4 of Table 6.3 and group 0 and group 1 steels to be used at low temperatures
2. IS : 3609 - 1966 Specification for chrome molybdenum steel, seamless boiler and superheater tubes
3. IS : 2611 - 1964 Specification for carbon chromium molybdenum steel forgings for high temperature service.

iii) *High alloy corrosion and heat resistant steels*

1. Grade 07Cr13 IS : 1570-1961*
2. Grade 04Cr19Ni9 IS : 1570-1961*
3. Grade 04Cr19Ni9Ti20 IS : 1570-1961*
4. Grade 04Cr19Ni9Nb40 IS : 1570-1961*
5. Grade 07Cr19Ni9Mo2Ti28 IS : 1570-1961*
6. Grade 05Cr18Ni11Mo3 IS : 1570-1961*
7. Grade 05Cr18Ni11Mo3Ti20 IS : 1570-1961*
8. Grade 10Cr25Ni18 IS : 1570-1961*

Qualification in material of a higher alloy group also qualifies for material of a lower alloy group.

b) *Non-ferrous metals* — Whenever welding of non-ferrous metals is undertaken, the manufacturer shall prove to the inspecting authority that the welding is successfully

*Schedules for wrought steels for general engineering purposes.

undertaken by him as regards methods, filler metals, thickness of parent metal and equipment. For this purpose test welds shall be made in accordance with the limitations as agreed to between the manufacturer and the inspecting authority.

c) *Type and number of test specimens* — The type and number of test specimens that shall be tested to qualify a procedure qualification are given in Table 7.1 together with the range of thickness that is qualified for use in construction by a given thickness of test plate or pipe used in making the qualification. Qualification on pipe shall qualify for plate but not *vice versa*. The test specimens shall be removed in the order shown in Fig. 7.2 to 7.6.

d) *Welds between different base metals* — When joints are made between two different types of base metal, a welding procedure qualification shall be made for the applicable combination of materials even though procedure qualification tests have been made for each of the two types of base metals welded to itself.

7.1.3.2 *Electrodes, filler rods, flux and shielding gas* — The specification and if there is no suitable specification, the type and mark of electrode and the composition of the filler rods, flux and shielding gas, shall be the same for the procedure qualification and production welds.

7.1.3.3 *Type of joint preparation* — For manual metal arc welding process, the type of joint preparation, for example, single V, double V, single U, double U or square edge, may be changed in production welds without the necessity of making a new procedure qualification test, provided that the form of the preparation is in agreement with good practice. For semi-automatic or automatic welding process, any important change in edge preparation requires a new procedure qualification.

7.1.3.4 *Welding technique* — A new procedure qualification test shall be required:

a) if in metal arc welding with covered electrodes a change in the type of electrode or a change in the composition of the weld metal, and in gas welding, a change in filler metal type or a change in weld metal composition is made;

b) if in arc welding a change is made from dc source to ac or *vice versa*;

c) if in arc welding of single welded butt joints a backing strip is added or omitted;

d) if in oxy-acetylene welding of single welded butt joints a backing strip is added;

e) if in machine welding a change is made from multiple pass welding per side to single pass welding per side;

f) if in submerged arc welding, a change is made from a filler metal containing 1·75 to 2·25 percent manganese to filler metal containing less than one percent manganese or *vice versa* (the presence of 0·5 percent molybdenum in the filler metal analysis shall not require requalification);

g) if in submerged arc-welding, a change is made in the nominal composition or type of flux used or a change is made in filler metal analysis (requalification is not required for the change in flux particle size);

NOTE — In submerged arc-welding, where the alloy content of the weld metal is largely dependent upon the composition of the flux used, any change in any part of the welding procedure which would result in the important alloying elements in the weld metal being outside the specification range of chemistry given in the welding procedure specification. If there is evidence that production welds are not being made in accordance with the procedure specifications, the inspector may require that a check be made on the chemical composition of the weld metal. Such a check shall preferably be made on a production weld.

h) if in inert gas metal arc welding a change is made in the composition of the gas and a change in the electrode from one type to another or from non-consumable electrode to consumable electrode and *vice versa*.

7.1.3.5 *Welding process* — The welding process and, in the case of manual semi-automatic or automatic welding, the type of welding device shall be the same for the procedure qualification test and for the production welds. When the root pass of combination welds is made by one process and the remaining portion of the groove by another process, a new procedure qualification test is required.

7.1.3.6 *Preheating and delayed cooling* — The temperature of preheating, and heat treatment immediately following welding and any control of cooling rate, shall be the same for the procedure qualification test and for the production welds. However, if the preheat temperature in production work is increased by less than 100°C this change will not necessitate a new procedure qualification test.

7.1.3.7 *Subsequent heat treatment* — The subsequent heat treatment shall be the same for the welding procedure test and the production welds.

7.1.4 For metal arc welding, a procedure qualification shall be valid for thickness from 0·75 to 1·5 times the thickness of the procedure qualification test piece in plate or pipe. For oxy-acetylene welding the test piece thickness shall be the maximum thickness for which the procedure qualifications are valid.

7.1.5 The test pieces for procedure qualification for butt welds in plates shall be of sufficient size to provide for the following tests:

a) One reduced-section tensile test specimen cut transversely to the weld or as many specimens as are necessary to investigate the tensile strength over the whole thickness of the joint for all plate thicknesses (*see* **8.5.7**).

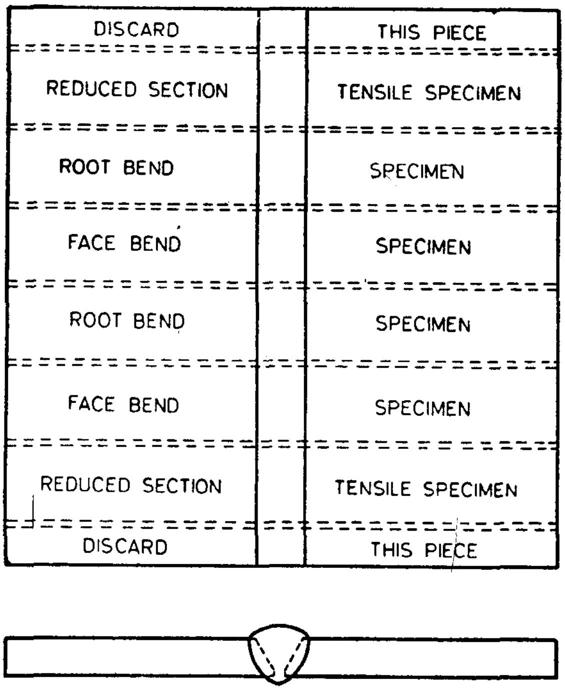


FIG. 7.2 ORDER OF REMOVAL OF TEST SPECIMENS FROM WELDED TEST PLATE

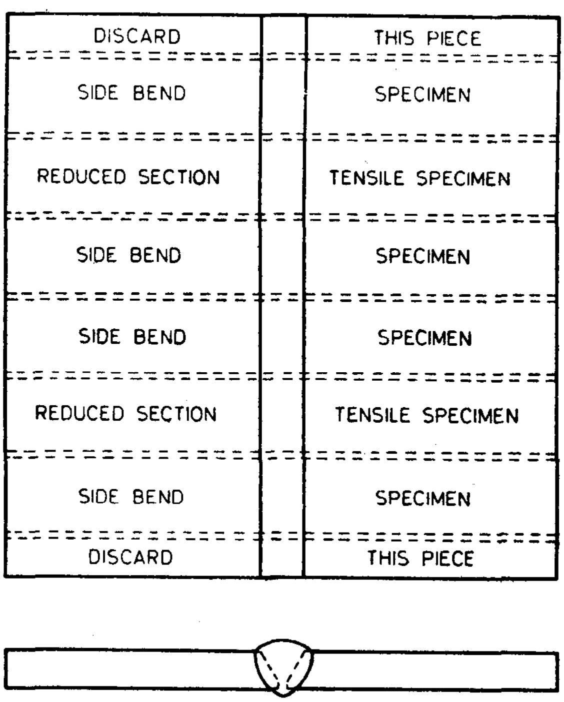


FIG. 7.3 ORDER OF REMOVAL OF TEST SPECIMENS FROM WELDED TEST PLATE

b) One all-weld metal tensile test specimen when the plate thickness is between 10 and 70 mm inclusive; two test specimens, one above the other, in case where the plate thickness is more than 70 mm. The dimensions of the all-weld metal tensile test specimens shall be those shown in Fig. 7.7. The diameter d_0 shall be the maximum possible consistent with the cross section of the weld (*see* IS : 1608-1960*). The gauge length shall be equal to five times the diameter (*see* **8.5.6**).

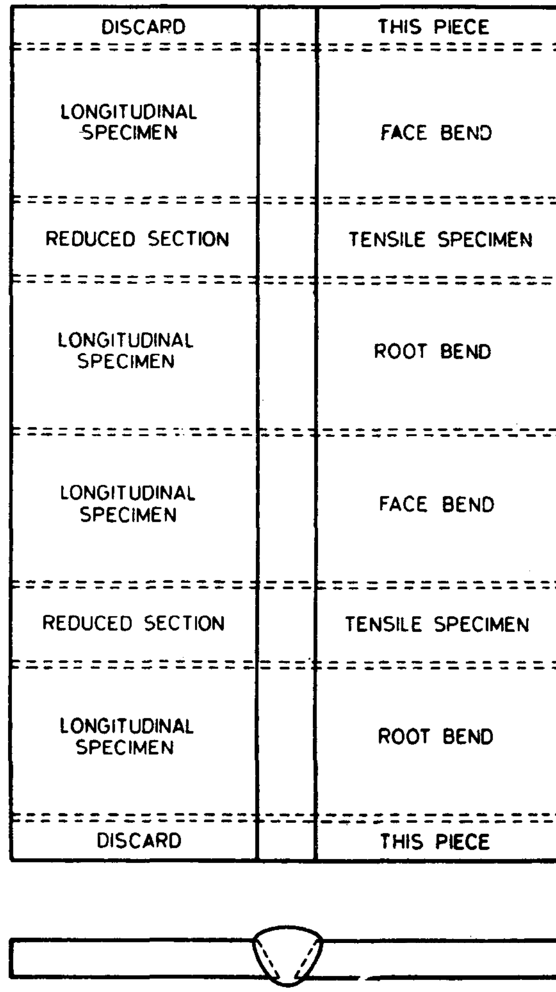


FIG. 7.4 ORDER OF REMOVAL OF TEST SPECIMENS FROM WELDED TEST PLATE

c) Two bend test specimens, one for direct and one for reverse bending to be taken transversely to the weld, and where the thickness of the plate permits, one shall be above the other:

1) When the thickness of the plate exceeds 30 mm face bend and root bend tests may be substituted by side bend tests. When welds are made from one side only, one bend test may be a side bend test but at least one shall be a normal bend test with the root of the weld in tension (*see* **8.5.9**).

2) If desired by the purchaser, the guided bend test specimens for face, root and

*Method for tensile testing of steel products other than sheet, strip, wire and tube.

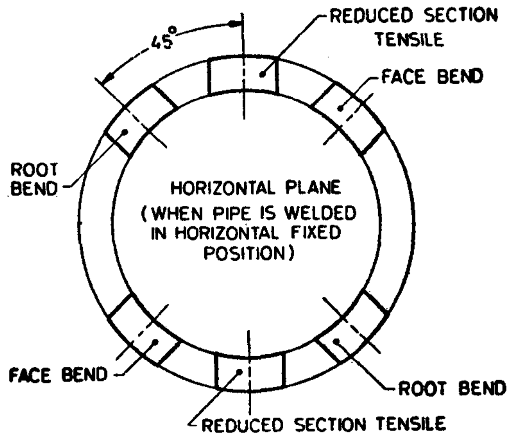


FIG 7.5 ORDER OF REMOVAL OF TEST SPECIMENS FROM WELDED PIPE

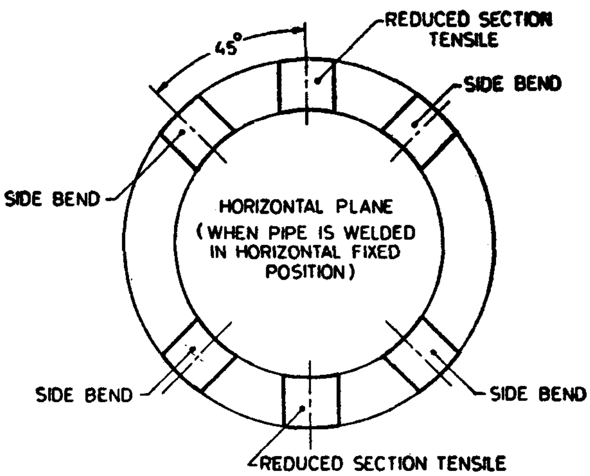


FIG. 7.6 ORDER OF REMOVAL OF TEST SPECIMENS FROM WELDED PIPE

side bend test for plates may be used for austenitic chromium nickel vessels (*see* **8.5.9.6**). The test plates for austenitic steel vessels should be welded by the procedure used in the longitudinal joints of the vessels and should be heat-treated using the same temperature cycles as used for the vessels. The operations on the test plate should be such as to duplicate as closely as possible, the physical conditions of the material in the vessel.

d) Three notched bar impact test specimens to be taken transversely to the weld (*see* **8.5.8**).

e) One macro-test specimen (*see* **8.5.11**).

The macro-test specimens prescribed shall also be used to make Vickers hardness tests along the cross section of the weld and the heat affected zone. The hardness shall be assessed by a HV indenter of not more than 30 kgf load (*see* **7.1.5.5**).

7.1.5.1 *All-weld metal tensile tests* — The tensile strength R obtained shall be at least equal to the specified minimum tensile strength of the base material. The elongation A in percent obtained shall be at least equal to that given by the equation in the case of carbon and carbon manganese steels:

$$A = \frac{100 - R}{2 \cdot 2}$$

R being measured in kgf/mm².

In addition, this elongation shall not be less than 80 percent of the equivalent elongation given for the base material.

7.1.5.2 The type and number of test specimens that shall be tested to qualify a procedure qualification are given in Table 7.1 together with

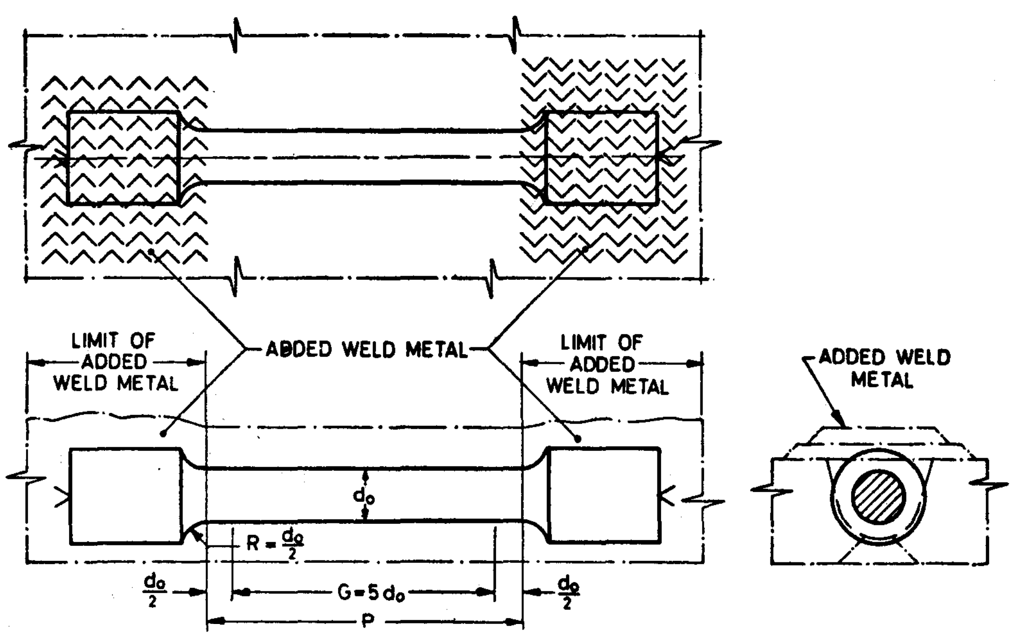


FIG. 7.7 ALL-WELD METAL TENSILE TEST PIECE

TABLE 7.1 TYPE AND NUMBER OF TEST SPECIMENS AND RANGE OF THICKNESS QUALIFIED FOR WELDING PROCEDURE QUALIFICATION FERROUS MATERIALS

[*Clauses* 7.1.3.1 (c) *and* 7.1.5.2]

Thickness t of Test Plate in mm	Range of Thickness Qualified by Test Plate in mm		Number of Test Specimens						
	Min	Max	Reduced Section Tensile Test (*see* **8.5.7**)	All-Weld Metal Tensile Test (*see* **8.5.6**)	Face Bend (*see* **8.5.9**)	Root Bend (*see* **8.5.9**)	Side Bend (*see* **8.5.9**)	Impact Test (*see* **8.5.8**)	Macro and Hardness Test (*see* **8.5.11**)
Over 1·5 up to and including 10	0·75 t	2 t	1	1*	1	1	—	3†‡	1
Over 10 but less than 20	0·75 t	2 t	1	1	1	1	—	3‡	1
20 and over	0·75 t	2 t	1	1	—	—	2§	3‡	1

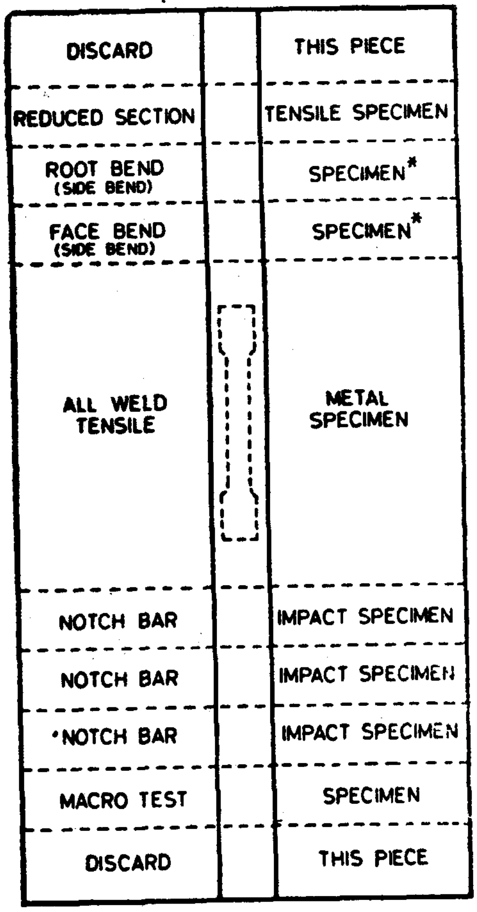
*For test plates 10 mm and above [*see* **7.1.5** (b)].

†For test plates less than 10 mm (*see* **8.5.8.1**).

‡Out of three test specimens, two specimens to contain the face side of the joint and one specimen to contain the root side of the joint.

§Either the face and root bend or the side bend tests may be used for thickness from 10 to 20 mm.

the range of thickness that is qualified. The order of removing test pieces from test plates is shown in Fig. 7.8.



**See* Table 7.1.

FIG. 7.8 ORDER OF REMOVAL OF TEST SPECIMEN FROM WELDED TEST PLATE (PROCEDURE QUALIFICATION)

7.1.5.3 *Pipes and tubes* — The test pieces for procedure qualification for butt welds in pipes and tubes shall consist of two pieces of the pipe or tube joined by a circumferential butt weld and shall provide for the number of test specimens given in Table 7.2.

TABLE 7.2 NUMBER OF TEST SPECIMENS OF TUBES OR PIPES

Pipe Diameter (Outside)	Cross Tensile Test	Face Bend Test (*see* **8.5.9**)	Root Bend Test (*see* **8.5.9**)	Macro Etc. (*see* **8.5.11**)
Up to 50 mm	1*	—	2	1
Over 50 mm	2	1	3	1

*The cross tensile test piece for small tubes shall be the welded pipe as a whole.

A separate piece of welded pipe or tube shall be required to provide the root bend and macro-etch test specimens in the case of small pipes or tubes.

If a backing ring is used, it shall be left in position in the macro-etch specimen and in the tensile test made on a welded pipe as a whole; from all other test specimens the backing ring shall be removed.

The tensile test specimens shall be made in accordance with **7.1.5** (b) except that the minimum width shall be 20 mm.

The bend test specimens shall have the width specified in Table 7.3.

TABLE 7.3 WIDTH OF BEND TEST SPECIMENS IN TUBES OR PIPES

Pipe Diameter D Outside	Thickness t of Pipe	Width of Bend Test Piece
Up to 50 mm	t	$t + \frac{D}{10}$
Over 50 mm	t	$t + \frac{D}{20}$ with a maximum of 40 mm

The bend test pieces shall be out with the edges parallel as in Fig. 7.9 and shall have the corners rounded or dressed to a radius of approximately 2 mm.

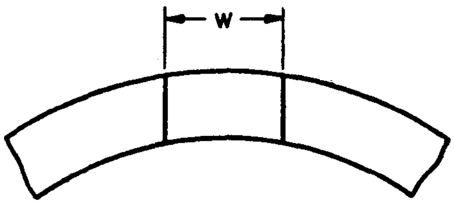


FIG. 7.9 CUTTING OF BEND TEST PIECES

The bend test pieces shall be bent without being straightened, but after removal of the weld reinforcements down to the level of, but not below, the surface, round a former of diameter 3*t* and through an angle of 90 degree in the case of carbon steels.

In case of alloy steels the bend angle shall be as agreed to between the manufacturer and the inspecting authority.

The manner in which the test specimen shall be taken from test pieces is indicated in Fig. 7.10.

150 units for steels of material group 2

200 units for steels of material group 3 and 4

7.1.6 The test pieces for procedure qualification are subject to radiography of the weld, if the production weld is subjected to radiography or if the inspecting authority considers this necessary (*see* **8.7**).

7.1.7 The results of the tests and examination of welding procedure qualification test piece shall satisfy the requirements for welded production test plates (*see* **8.6**).

7.1.8 If the results of procedure qualification test are in any way unsatisfactory, the welding procedure qualification shall be completely repeated.

7.1.8.1 Retesting of specimens, taken out of the same procedure test coupon, is not allowed. However, the causes of unsatisfactory results should be investigated.

7.1.9 A completely new welding procedure qualification shall be necessary in case there is a change in essential variables described under **7.1.3**.

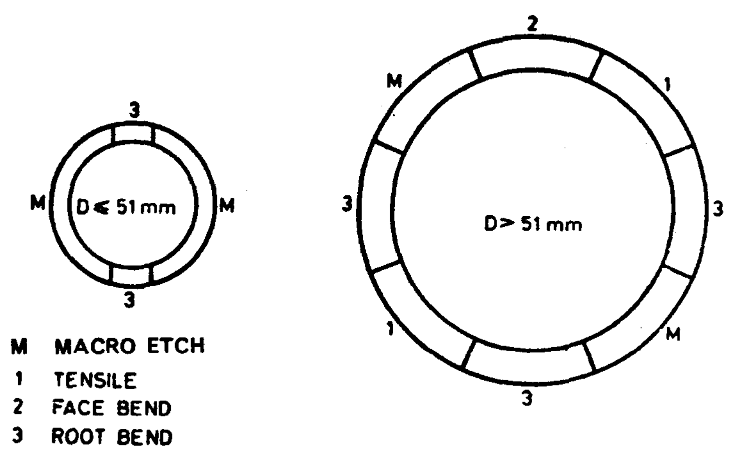


FIG. 7.10 MANNER OF TAKING TEST SPECIMENS FROM TUBES AND PIPES

7.1.5.4 The macro-etch test specimen shall be taken from that part of the periphery of the weld that corresponds to what is regarded as the most difficult welding position in the case concerned.

The inspecting authority at his discretion may call for an additional test position in case of butt welded pipes, that is, pipe inclined at 45° to the horizontal. Welding shall be done without rotating the pipe (*see* Fig. 7.1F).

7.1.5.5 The maximum Vickers hardness value of the weld metal and heat affected zone shall not exceed that of the parent metal by more than the following values:

120 units for steels of material group 0 and 1 (*See* Table 6.3)

7.1.10 Records of all tests shall be kept by the manufacturer for a period of at least 5 years after the inspection of pressure vessels and shall be available for the inspecting authority for examination, when required. Suggested form for records is given in Appendix H.

7.2 Welder's Performance Qualifications

7.2.1 Where a manufacturing firm furnishes proof, satisfactory to the customer and the inspecting authority, that all welders assigned to manual or machine welding on pressure vessels and pressure parts have previously made performance qualification test for the type of work and procedure concerned, or have also been successfully engaged in the manufacture of pressure vessel for a period of six months in

accordance with the requirements of this code then all such welders shall be exempt from the necessity of requalifying under these rules so long as the welders remain in the employment of the same manufacturer provided that all welder's tests shall have been carried out on testing machines having a valid calibration certificate and the welding of test pieces has been carried out in the presence of inspecting authority. Where such proof is not forthcoming, welders assigned to manual or machine welding on pressure vessels and pressure parts shall have successfully passed the welder's performance test for the type of work and procedure concerned.

7.2.2 The required tests shall be repeated if in the course of the previous six months the records of the welder show unsatisfactory production work, or if the welder has not been employed by the same manufacturer on the same type of work for a period of six months or more.

7.2.3 The welder's qualification at **7.2.1** holds only as long as the welder remains in the employment of the same manufacturer.

7.2.4 Test welds for welders performance qualification shall be carried out in exactly the same way and under the same conditions as laid down for the welding procedure qualification, except for the type of joint in the case of fillet welds and branch welds (*see* **7.2.6** and **7.2.10**).

7.2.4.1 *Welding operators* — Each welding operator who welds on vessels constructed under the rules of this code shall be examined as follows for each welding procedure under which he does welding with machine-welding equipment in which both the rate of travel and the position of the welding head with respect to the work are controlled mechanically, except for minor adjustments for such factors as plate-uneveness, out-of-roundness, and lead-angle:

A) A 900 mm length of weld made by the operator shall be examined by radiography or by sectioning. The length of weld so examined may be that of a test plate or of production welding.

B) In order to ensure that the operator carries out the provisions of the welding procedure, the radiographs of the joint shall be made in accordance with the technique prescribed under **8.7** and shall meet the requirements for spot radiographic examination given in (a) or two transverse sections, taken at approximately the third point of the weld, shall meet the requirements for sectioning given in (b):

a) *Requirements for spot radiographic examination*

1) Welding in which the radiographs show any type of crack or zone of incomplete penetration shall be unacceptable.

2) Welds in which the radiographs show slag inclusions or cavities shall be unacceptable if the length of any such imperfection is greater than 2/3 t where t is the thickness of the thinner plate welded. If several imperfections within the above limitations exist in line, the welds shall be judged acceptable if the sum of the longest dimensions of all such imperfections is not more than t in a length of $6t$ (proportionately for radiographs shorter than $6t$) and if the longest imperfections considered are separated by at least $3L$ of acceptable weld metal, where L is the length of the longest imperfection. The maximum length of acceptable imperfection shall be 20 mm. Any such imperfections shorter than 6 mm shall be acceptable for any plate thickness.

3) Porosity shall meet the requirements laid down under **8.7.5.3** and **8.7.5.4**.

b) *Requirements for sectioning*

1) When the welded joint is to be examined by sectioning, the specimens removed shall be such as to provide a full cross section of the welded joint and may be removed by trepanning a round hole or by any equivalent method.

2) The specimens shall be ground or otherwise smoothened and then etched by any method or solution which will reveal the defects without unduly exaggerating or enlarging them (*see* Appendix K).

3) If the sections are oxygen-cut from the vessel wall, the opening in the vessel wall shall not exceed 40 mm on any diameter or the width of the weld, whichever is greater, as measured after removal of all loose scale and slag accumulation. Oxygen-cut specimens shall be sawn across the weld to obtain a plane surface which will expose the full width of the weld on the cut surface.

4) Sections removed from the welded joint shall not show any types of cracks or zones of incomplete fusion or inadequate joint penetration. Gas pockets and slag inclusions shall be permissible only:

i) when the width of any single slag inclusion between layers of weld metal substantially parallel to the plate surface is not greater than one-half of the width of the sound weld metal where the slag inclusion is located;

ii) when the total thickness of all of the slag inclusion in any plane at approximately right angles to the plate surface is not greater than 10 percent of the thickness of the thinner plate; and

iii) when there are gas pockets that do not exceed 2 mm in greatest dimension and when there are not more than six gas pockets of this maximum size per 650 mm^2 of the weld metal or when the combined areas of a greater number of pockets do not exceed 13 mm^2 per 650 mm^2 of weld metal.

5) The segments or plugs after removal shall be properly stamped or tagged for identification and, after etching, kept in proper containers, with a record of their place of removal as well as of the welding operator who performed the welding.

C) If the weld does not meet the requirements set forth in **7.2.4.1** (B) second and subsequent joints, welded by the operator using the machine welding procedure, shall be examined by the same method until the operator demonstrates that he is capable of producing acceptable welds. (Production welds so examined shall be unacceptable if they do not meet the minimum requirements of this code.)

D) The results of the radiographic or sectioning examination shall be recorded and the radiographs or sectioned specimens may be retained or be discarded by the manufacturer.

Welds requiring a combination of processes may be performed by one or more welders or welding operators. Each, however, may do only that portion of the weld for which he has been qualified.

7.2.5 For welder's performance qualification, test welds of the butt welded types in plates shall have length of at least 300 mm and not less than five times the plate thickness to provide necessary test pieces. These test welds shall be submitted for visual and radiographic examination (*see* **8.7**) and to macro-etching of a cross section of the weld.

7.2.5.1 The types and number of test specimens that shall be tested to qualify welders' performance qualification are given in Table 7.4.

7.2.5.2 In case of oxy-acetylene welds and welds deposited from one side only, as many root bend tests shall be made in addition as the size of the test coupon permits. The root bend test specimens shall conform to those required for testing of welded production test plates (*see* **8.5.9**):

a) Test welds of the butt welded type for welder's performance qualification on pipes or tubes, shall be tested by means of bend test pieces of the number, width and conditions of bending, exactly in accordance with **7.1.5.3**.

b) The range of thickness qualified by test butt welds on pipes or tubes shall be as given below:

Thickness of Pipe, t, as Welded, in mm	*Range of Thickness Qualified, in mm*	
	Min	*Max**
Up to 10	1·5	2 *t*
Over 10 but less than 20	5	2 *t*
20 and over	5	1·5 *t*

7.2.6 Test welds for welder's performance qualification in fillet welds shall be carried out to check the size, contour and degree of soundness of the fillet welds. The test welds shall be broken and the appearance of the rupture, as well as a macro-etching of a cross section of the weld, examined.

7.2.6.1 The test fillet welds shall be made in the following basic position. The limits of angular variation of the planes during welding shall be as given in IS : 815-1966†.

a) *Flat position* — Plates so placed that the weld is deposited with its axis horizontal and its throat vertical (*see* Fig. 7.11A).

b) *Horizontal position* — Plates so placed that the weld is deposited with its axis horizontal on the upper side of the horizontal surface and against the vertical surface (*see* Fig. 7.11B).

c) *Vertical position* — Plates so placed that the weld is deposited with its axis vertical (*see* Fig. 7.11C).

d) *Overhead position* — Plates so placed that the weld is deposited with its axis horizontal on the underside of the horizontal surface and against the vertical surface (*see* Fig. 7.11D).

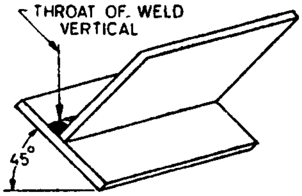
*For gas welding the maximum range of thickness qualified shall be limited to 1·25 times the test plate thickness.

†Classification and coding of covered electrodes for metal arc welding of mild steel and low alloy high tensile steel (*revised*).

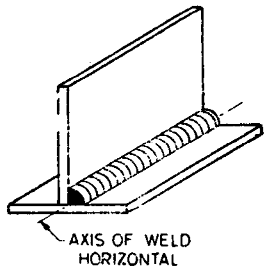
TABLE 7.4 TYPES AND NUMBER OF TEST SPECIMENS AND RANGE OF THICKNESS QUALIFIED (WELDER'S PERFORMANCE QUALIFICATION)

Type of Joint	Thickness of Test Plate *t*, mm	Range of Thickness Qualified by Test Plate		Number of Test Specimens		
		Min	*Max*	Root Bend (*see* **8.5.9**)	Face Bend (*see* **8.5.9**)	Nick Break (*see* **8.5.10**)
Butt weld	*t* up to 10	3	2 *t*	1	1	1
	t over 10 but less than 20	5	2 *t*			
	t 20 and over	5	1·5 *t*			
Fillet weld	7	All thickness		—	—	—

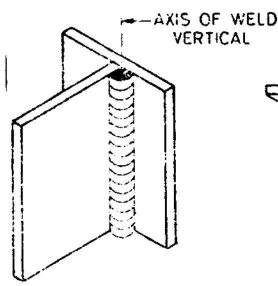
7.2.6.2 Qualification in the horizontal, vertical or overhead positions shall qualify also for the flat position.



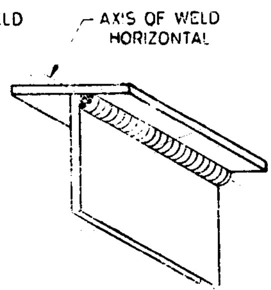
7.11A Flat Position of Test Tee for Fillet Weld



7.11B Horizontal Position of Test Tee Fillet Weld



7.11C Vertical Position of Test Tee for Fillet Weld



7.11D Overhead Position of Test Tee for Fillet Weld

FIG. 7.11 POSITIONS OF TEST PLATES FOR WELDER PERFORMANCE QUALIFICATION OF FILLET WELDS

7.2.6.3 The welds shall satisfy the following test. The dimensions and preparation of fillet weld test specimen shall be as shown in Fig. 7.12. The test specimen shall not contain any visible cracks. The test piece shall be cut transversely to provide a centre section of 25 cm length:

a) *Fracture test* — The stem of the 25-cm centre section shall be loaded laterally in such a way that the root of the weld is in tension. The load shall be steadily increased until the specimen fractures or bends flat upon itself. In order to pass the test:

   i) the specimen shall not fracture; or

   ii) if it fractures, the fractured surfaces shall show no evidence of cracks or incomplete root fusion, and the sum of the lengths of inclusions and gas pockets visible on the fractured surface shall not exceed 50 mm in length.

b) *Macro-examination* — The cut end of one of the end sections shall be smoothened and etched with a suitable etching agents* to give a clear definition of the structure of the weld. In order to pass the test:

   i) visual examination of the cross section of the weld shall show complete fusion at the root and freedom from cracks;

   ii) the weld shall not have a concavity or convexity greater than 1·5 mm; and

   iii) there shall be not more than 1·5 mm difference in the lengths of the legs of the fillet.

7.2.6.4 The test for welder's performance qualification in branch welds shall be carried out to conform to one of the following methods:

a) The weld shall be made on an assembly conforming to one of the types adopted by the manufacturer in his construction. The test specimen shall be approximately 200 mm in diameter and 20 mm thick for the branch and approximately 20 mm thick for the plate. This test would qualify the welder for branches of this same general design of connection.

b) A weld shall be made on a test plate of the dimensions shown in Fig. 7.13 and shall be accepted for qualifying a welder to make set-in branch welds.

   A weld on a test piece of the dimensions shown in Fig. 7.13B will qualify a welder for welding set-on branches.

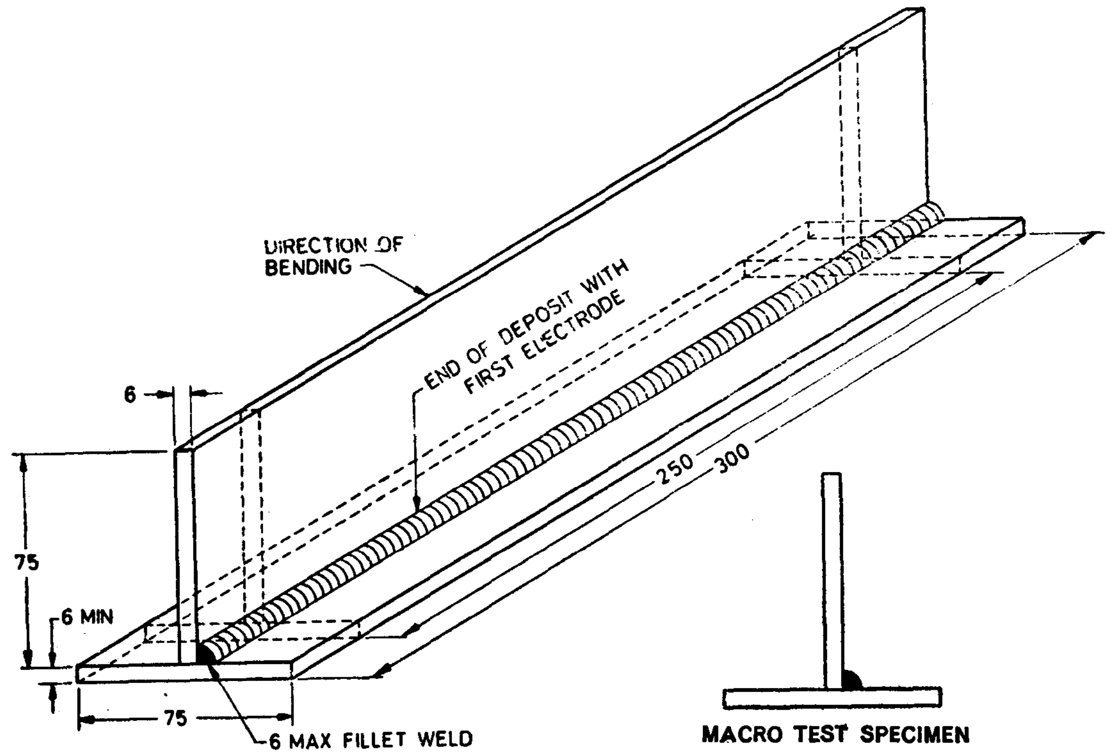
c) A weld shall be made between two branch pipes as shown in Fig. 7.13C. The size of main pipe shall not be less than 127 mm outside diameter and 10 mm thick and the outside diameter of branch pipe shall not be less than 89 mm on outside diameter and 6 mm thick. The test joint shall be welded using the type of welding groove specified in the welding procedure specification.

   For welds made in accordance with (a) the test pieces shall be submitted to a visual examination and a macrographic examination on transverse section, and for welds made in accordance with (b) a radiographic examination (*see* **8.7**). The macrographic examination shall include, for welds made in accordance with (a), four macrographs on sections taken at right angles; and for welds made in accordance with (b) two macrographs from each test piece taken as shown in Fig. 7.13A and 7.13B and for welds made in accordance with (c) four macrographs as shown in Fig. 7.13C.

7.2.7 All test welds for welder's performance qualification shall be carried out with equivalent electrodes, filler rods, flux and shielding gas, as used for the procedure qualification and the production welding concerned.

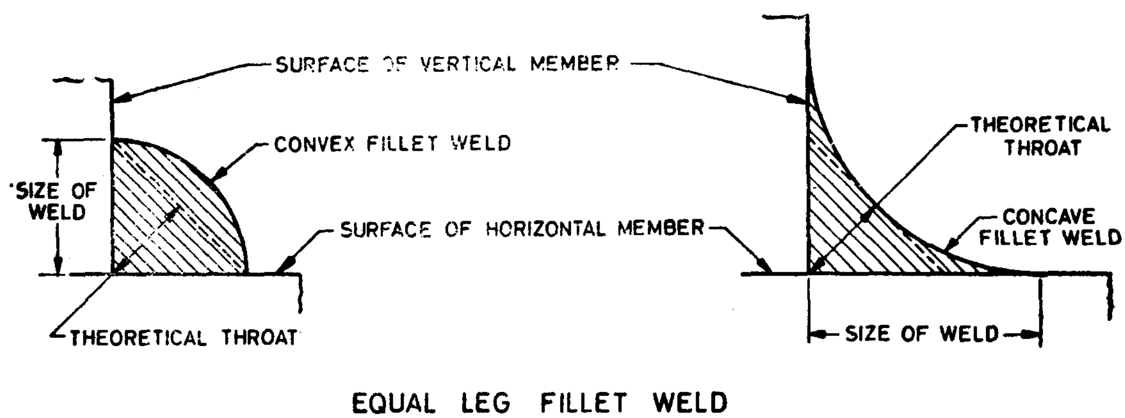
7.2.8 The appearance of the test welds, the macrographs, and the radiographs of these test welds where required, shall conform to the requirements for acceptance of the production welds.

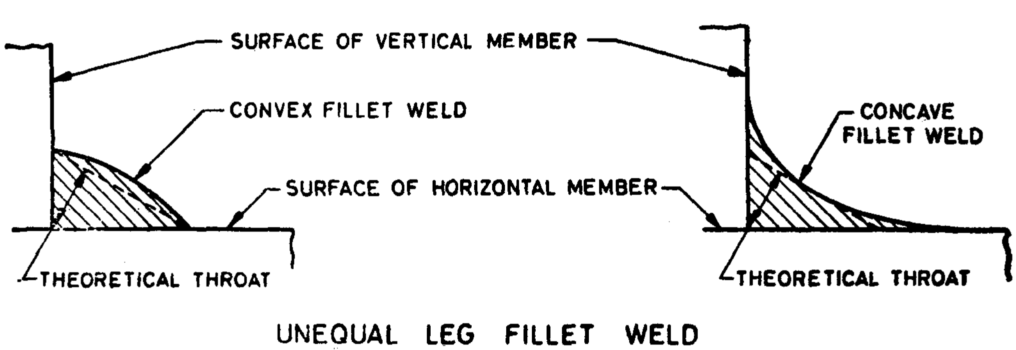
*Suitable etching agents are given in Appendix K.



All dimensions in millimetres.

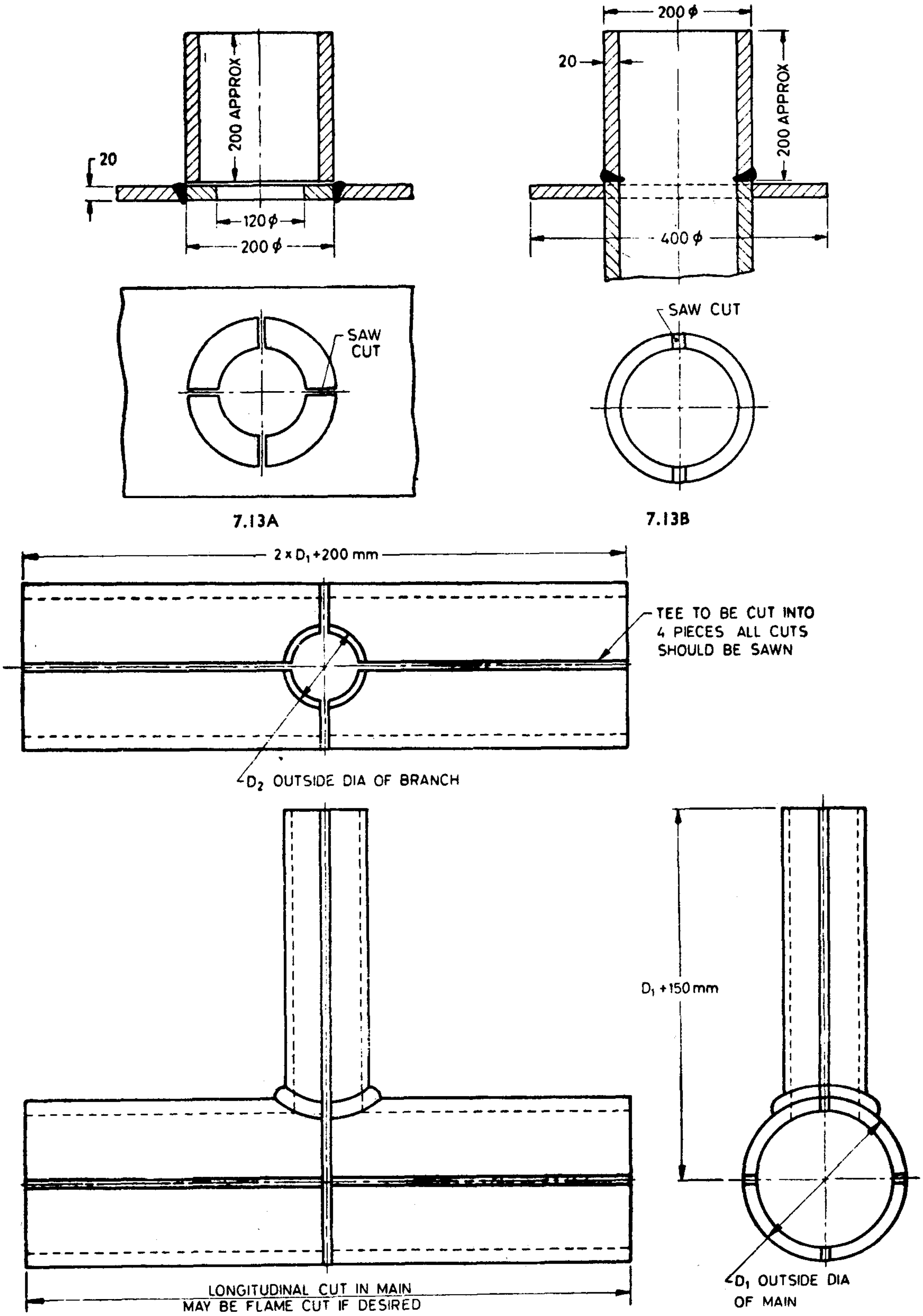
7.12A Fillet Weld Soundness Test for Performance Qualification of Welders





7.12B Equal and Unequal Leg Fillet Weld Sizes

FIG. 7.12 FILLET WELDS



All dimensions in millimetres.

Fig. 7.13 Welders Performance Test Specimen

7.2.8.1 *Retests* — A welder who fails to meet the requirements for one or more of the test specimens prescribed in Table 7.4 may be tested under the following conditions:

a) When an immediate retest is made, the welder shall make two test welds of each type for each position on which he has failed, all of which shall pass the test requirements.

b) When the welder has had further training or practice, a complete retest shall be made for each position on which he failed to meet the requirements.

7.2.9 Requalification of welder's performance will have to take place in case of requalification of the welding procedure due to a substantial change in essential variables as listed in **7.1.3**.

7.2.9.1 *Essential variables* — A welder shall be requalified whenever one or more of the changes listed below are made in the performance specification:

a) The addition of other welding positions than those already qualified under **7.2.6.1**.

b) The omission of backing strip in metal-arc welding single welded butt joints.

c) The addition of backing strip in gas welding.

d) A change from one welding process to any other welding process or a combination of welding processes.

e) Where a combination of welding processes is required to make a weldment, each welder or welding operator shall be qualified for the particular welding process he is required to perform in production welding.

f) A change from any non-consumable process to any consumable-electrode process or *vice versa*.

g) Where combination welds are used, the welder or welding operator who is to make the root pass shall be tested only by means of a minimum of two root bends instead of the face bends and side bends listed in Table 7.4.

h) In any welding process, the omission or addition of consumable backing rings or strip.

j) The omission of inert gas backing.

7.2.10 A welder having carried out a welding procedure qualification with good results will also be qualified for welder's competence in the procedure concerned, except in the case of branch welds.

7.2.10.1 Welder who passes the tests for butt welds shall also be qualified to make fillet welds in all thicknesses. Welder who passes the tests for fillet welds shall be qualified to make fillet welds only.

7.2.10.2 *Renewal of qualification* — Renewal of qualification of a performance qualification is required (a) when a welder or welding operator has not used the specific process, that is, metal arc, gas, submerged arc, etc, to weld either ferrous or non-ferrous materials for a period of six months or more, or (b) when there is a specific reason to question his ability to make welds that meet the specification. Renewal of qualification under (a) need be made in only a single test-plate thickness.

7.2.11 Records of all tests shall be kept by the manufacturer and shall be available for the inspecting authority for examination whenever required. Suggested form for the records is given in Appendix H.

7.2.11.1 Each qualified welder and welding operator shall be assigned one identifying number, letter or symbol by the manufacturer which shall be used to identify the work of that welder or welding operator.

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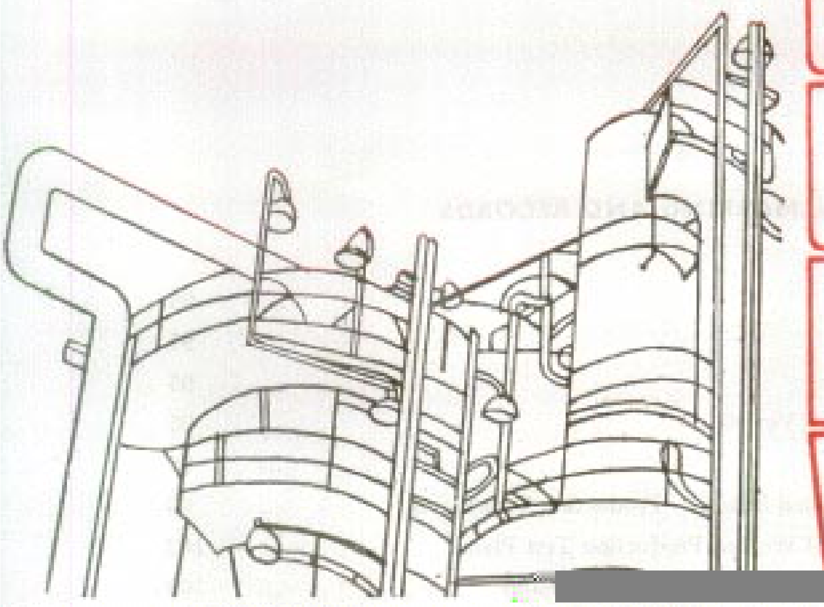
SECTION III INSPECTION, TESTS MARKING AND RECORDS

CODE FOR UNFIRED PRESSURE VESSELS



8. INSPECTION AND TESTS
9. MARKING AND RECORDS

SECTION III INSPECTION, TESTS, MARKING AND RECORDS

8. INSPECTION AND TESTS

8.1 General — Inspection shall be made at the various stages of construction depending on the classification of the vessel (*see* Table 1.1). The manufacturer shall keep the purchaser and/or the inspecting authority informed of the progress of the work and shall notify the inspector reasonably in advance when the vessel has reached the required stage for inspection.

8.2 Inspection During Manufacture — All materials to be used for pressure parts of vessels shall be inspected before fabrication for the purpose of detecting defects which may affect the safety of the vessel.

8.2.1 Special attention shall be paid to the cut edges and other parts of rolled material which may disclose the existence of serious laminations, shearing cracks and other objectionable defects.

8.2.1.1 Defects shall not be repaired unless inspected and approved by the inspecting authority. Material which, in the inspecting authority's opinion, cannot be satisfactorily repaired shall be deemed not to comply with the requirements of this code.

8.2.2 *Identification of Materials* — The inspector shall ensure that all material before use is properly identified as complying with the code requirements. Mill certificates or other test certificates to the satisfaction of the inspecting authority shall be produced to identify the material, The manufacturer's identification marks should not be obliterated during manufacture. Where necessary the marks shall be transferred in the presence of the inspector. Steel plate less than 7 mm thick or non-ferrous plate less than 12 mm thick shall not be deep die stamped and the depth of stamping shall not exceed 0·5 mm.

8.2.2.1 The inspector shall witness the marking of, and place his own stamp on portions of the parent plate intended to be used as test plates for seams. The mark should be so located that it will not be cut out or obliterated during fabrication.

8.2.3 *Inspection During Fabrication*

8.2.3.1 The inspector shall make inspections of each vessel at such stages of fabrication as he deems necessary to assure himself that the fabrication is according to code requirements.

8.2.3.2 The edges of plates, openings and fittings exposed during manufacture shall be examined for defects.

8.2.3.3 Before assembly, all shell sections, ends, rings, etc, shall be examined for conformity to prescribed shape and checked for thickness and dimensions.

8.2.3.4 The component parts of the vessel shall be assembled and checked for alignment of matching edges. Special attention shall be paid to assembly of branches and to their reinforcement.

8.2.3.5 When conditions permit entry into the vessel, as complete an examination as possible shall be made before the final closure.

8.2.4 *Heat Treatment Check*—The inspector shall satisfy himself that stress-relieving procedure or other heat treatment, as may be necessary, has been correctly carried out.

8.3 Inspection of Completed Pressure Vessels

8.3.1 *Visual Inspection* — During the final inspection of the whole vessel the surfaces of the welds are to be inspected visually and judged as stated under **6.7.15**.

If irregularities are found, rectification shall be carried out (*see* **6.9**).

8.3.1.1 Records of manufacturing details, inspection and tests shall be kept by the manufacturer and shall be available for the inspecting authority for examination, whenever required. Manufacturer shall furnish a certificate of manufacture and production tests when requested in the form given in Appendix M.

8.3.2 *Radiographic Examination* — Radiographic examination of welded joints shall be carried out in the instances where required following the rules specified under **8.7**. Where so required by the inspecting authority the results of the radiographic examination shall be made available to him at the manufacturer's works.

8.3.2.1 All austenitic chromium nickel alloy steel welds in vessels whose shell thickness exceeds 20 mm, shall be examined for cracks by a suitable fluid penetration method.

8.4 Pressure Tests

8.4.1 The finished vessel shall, in the presence of the inspecting authority, pass satisfactorily such of the following pressure tests as may apply:

a) *Standard hydrostatic test* — for simple vessels where thickness of all pressure parts can be calculated.

b) *Proof hydrostatic tests* — for complex vessels the thickness of which cannot be computed with a satisfactory assurance of accuracy and for which the maximum working pressure has to be based upon the distortion pressure.

c) *Pneumatic tests* — for vessels so designed and/or supported that they cannot be safely filled with the testing liquid or for vessels that are to be used in services where even small traces of the testing liquid cannot be tolerated.

8.4.2 Pressure vessels in mild or low-alloy steels designed for internal pressure, shall be subjected to a hydraulic test pressure, which at every point

in the vessel is at least equal to 1·3 times the design pressure to be marked on the vessel multiplied by the lowest ratio of the allowable stress value f_1 of the material of construction at the test temperature to the allowable stress value f_2 at the design temperature.

$$\text{Test pressure in kgf/cm}^2 = 1{\cdot}3 \times \text{design pressure} \times \frac{f_1 \text{ at test temperature}}{f_2 \text{ at design temperature}}$$

8.4.2.1 The test pressure specified in **8.4.2** includes the amount of any static head acting at the point under consideration. If the weakest part of the vessel is not located at the lowest point of the vessel, it may be necessary to give special consideration to the effect of such additional static head due to the test liquid.

8.4.2.2 Vessels consisting of more than one independent pressure chamber operating at the same or different pressures and temperatures shall be so rested that each pressure chamber (vessel) receives the required hydraulic test with pressure in the others.

NOTE — It is important in the interest of safety that the vessel be properly vented so as to prevent formation of air pockets before the test pressure is applied. It is recommended that during the test the temperature of the water should not be below 15°C.

A hydraulic test based on a calculated pressure may be used by agreement between the purchaser and the manufacturer.

The vessel shall be maintained at the specified test pressure for a sufficient length of time to permit a thorough examination to be made of all seams and joints but in no case less than 10 minutes. Whilst under pressure, the vessel to be well hammered on both sides of and close to the welded seams. Hammer test is not required for vessels fabricated from materials which will be deleteriously affected by hammering and where the longitudinal and circumferential seams have been radiographed.

Single wall vessels and chambers of multi-chamber vessels designed for vacuum or partial vacuum only shall be subject to an internal hydraulic test pressure not less than 1·3 times the difference between normal atmospheric pressure and the minimum design internal absolute pressure, but in no case less than 1·5 kgf/cm². In case of jacketed vessels when the inner vessel is designed to operate at atmospheric pressure or under vacuum conditions, the test pressure need only be applied to the jacket space [*see also* **3.12.1**(c)].

8.4.3 *Pneumatic Tests*

8.4.3.1 Pressure testing with air or gas may be carried out in lieu of the standard hydraulic test in the following cases:

a) Vessels that are so designed, constructed or supported that they cannot safely be filled with water or liquid;

b) Vessels that are to be used in services where even small traces of water cannot be tolerated.

Such pneumatic pressure test shall be carried out under close supervision by the inspecting authority. Adequate precautions, such as blast walls or pits and means for remote observation are essential.

8.4.3.2 The pneumatic test pressure shall not be less than the design pressure but need not exceed test pressure in a hydraulic test.

8.4.3.3 *Procedure* — The pressure shall gradually be increased to not more than 50 percent of the test pressure. Thereafter the pressure shall be increased in steps of approximately 10 percent of the test pressure till the required test pressure is reached. Then the pressure shall be reduced to the value of the equivalent design pressure and held at the pressure for a sufficient time to permit inspection of the vessel.

8.4.4 *Combined Hydrostatic Pneumatic Test*

8.4.4.1 In some cases it may be desirable to pneumatically test a vessel partially filled with liquid. In such cases a pneumatic test may be applied to the space above the liquid level, the pneumatic test pressure being as required in **8.4.3.2** less the pressure due to the static head of the liquid contained.

8.4.4.2 When pressure testing small, mass-produced pressure vessels, the length of time for which the test pressure is to be maintained, may be reduced upon agreement with the inspecting authority in each individual case.

8.5 Mechanical Tests of Fusion Welded Seams — Production Test Plates

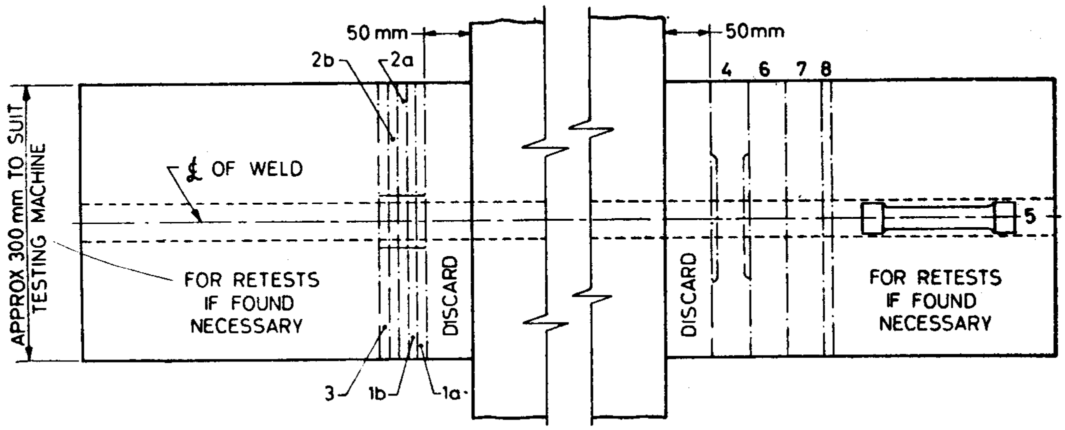
8.5.0 Fusion welded seams shall satisfy the following mechanical tests.

8.5.1 Vessels subjected to severe duty or with a weld joint efficiency factor $J = 0{\cdot}9$ to $1{\cdot}0$ shall be provided with two test plates to represent the welding of all the longitudinal seams of the first six shells or part thereof. Vessels with more than six shells shall have a test plate for every third additional shell or part thereof. No test plate need be provided for circumferential seams, except in cases where a pressure vessel has circumferential seams only or if the welding process, procedure and technique is different in which case two test plates are to be provided, each having a joint as far as possible a duplication of the circumferential seam.

8.5.1.1 Test plates shall be attached at one end of the longitudinal seam in such a manner that the edges to be welded are a continuation and duplication of the corresponding edges of the seam. Welding shall be effected in one reasonably continuous operation by the same process and the operator or operators. Location of test plates shall be as agreed to between the inspecting authority and the manufacturer.

8.5.1.2 Test plates shall be of a size sufficient for the preparation of all the production test specimens indicated in **8.5.1.3** and should include provision for retests, if any tests fail. Recommended layout of test pieces is shown in Fig. 8.1.

welding of entire longitudinal seams of the vessel. No test plate need be provided for circumferential seams in the same vessel provided the welding procedure is the same for longitudinal and circumferential seams.



1. 1*a* and 1*b* Impact (Outer Surface) Specimen
2. 2*a* and 2*b* Impact (Inner Surface) Specimen
3. Micro and Macro Specimen
4. Reduced Section Tensile Test
5. All-Weld Metal Tensile Test Specimen
*6. Bend Test Specimen — Face
*7. Bend Test Specimen — Root
8. Micro and Macro Specimen

**See* Table 7.1 and clause 7.1.5 (c).

Fig. 8.1 Layout of Test Plates for Severe Duty Vessels or Vessels with $J = 0{\cdot}9$ to $1{\cdot}00$

8.5.1.3 Weld test plates shall make provision for the following:

a) One all-weld metal tensile test (*see* **8.5.6**).

b) One reduced section tensile test specimen cut transversely to the weld, or as many specimens as are necessary to investigate the tensile strength over the whole thickness of the joint (*see* **8.5.7**).

c) Two bend test specimens, one for direct and one for reverse bending, to be taken transversely to the weld, and where the thickness of the plate permits, one shall be above the other.

When the thickness of the plate exceeds 30 mm, face bend and root bend tests may be substituted by side bend tests. When welds are made from one side only, one bend test may be a side bend test but at least one shall be a normal bend test with the root of the weld in tension (*see* **8.5.9**).

d) Three notched bar impact test specimens, to be taken transversely to the weld as near as possible to the face side of the last pass of the weld on outer and inner plate surface (*see* **8.5.8**).

e) One macro test specimen (*see* **8.5.11**).

8.5.2 Vessels subjected to medium duty or with a weld joint efficiency factor $J = 0{\cdot}8$ to $0{\cdot}85$ shall be provided with two test plates to represent all the

8.5.2.1 Test plates shall be prepared as in **8.5.1.2**. The layout of test specimens is suggested in Fig. 8.2.

8.5.2.2 Test plates shall make provision for the following:

a) One reduced section tensile test specimen cut transversely to the weld, or as many specimens as are necessary to investigate the tensile strength over the whole thickness of the joint (*see* **8.5.7**).

b) Two bend test specimens, one for direct and one for reverse bending to be taken transversely to the weld, and where the thickness of the plate permits, one shall be above the other. Where the plate thickness exceeds 30 mm, face bend and root bend tests may be substituted by side bend tests. When welds are made from one side only, one bend test may be a side bend test but at least one shall be a normal bend test with the root of the weld in tension (*see* **8.5.9**).

c) One nick break test specimen shall be cut transversely to the welded seam. It shall be the full thickness of the plate (*see* **8.5.10**).

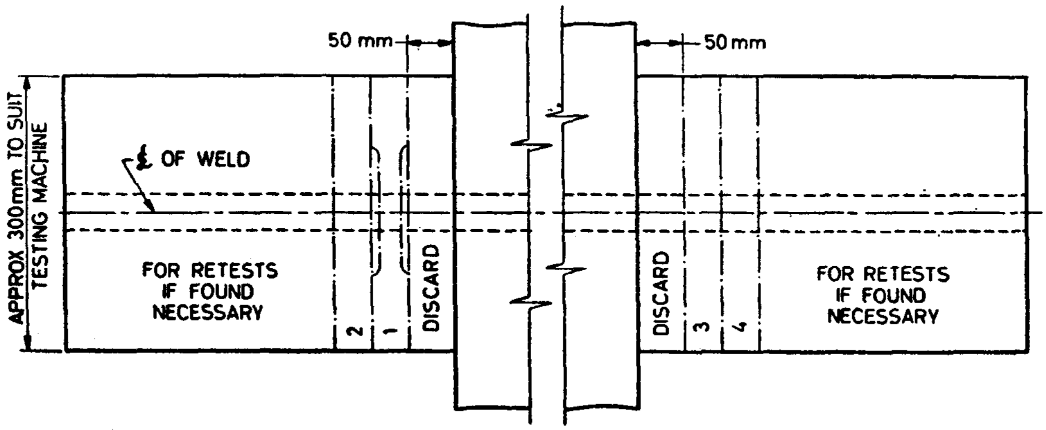
8.5.3 All conditions for the actual work piece and test plate shall be similar.

8.5.3.1 The material of the welded production test plate shall be of the same specification and the

same nominal thickness as that of the work piece, and may be taken from any part of one or more plates of the same lot of material that is used in the fabrication of the welded vessel.

8.5.4 The test plates shall be supported or reinforced during welding in order to prevent undue warping and distortion during welding (*see* Fig. 8.3).

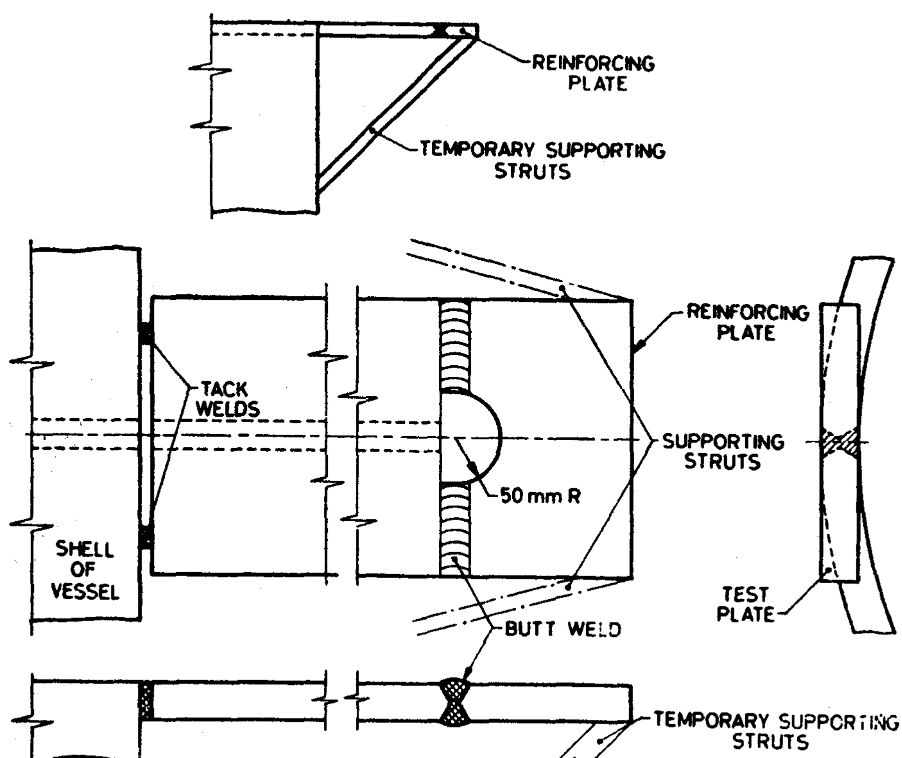
8.5.4.1 If it is desired to straighten test plates which have warped during welding, they may be straightened at a temperature below the temperature of heat treatment of the shell to which they belong. Straightening shall take place before final heat treatment. The test plates shall be subjected to the same heat treatment as required for the work piece they belong to.



1. Transverse Tensile Test Piece (Welded Joint)
*2. Bend Test Specimen — Face
*3. Bend Test Specimen — Root
4. Nick Break Specimen

**See* Table 7.1 and Clause 7.1.5(c).

FIG. 8.2 LAYOUT OF TEST PLATES FOR MEDIUM DUTY VESSELS OR VESSELS WITH $J = 0{\cdot}8$ TO $0{\cdot}85$



The test plates are to be suitably supported and reinforced to prevent distortion during welding. The test plates are to be tack-welded to the shell.

FIG. 8.3 METHOD OF SUPPORTING TEST PLATES

8.5.5 The welds in production test plates may be subjected to radiography (*see* **8.7**).

8.5.5.1 If any defects in the welds of a test plate are revealed by the radiographic examination, their position shall be clearly marked on the plate and test specimens shall be selected from such other parts of the test plate as may be agreed upon between the manufacturer and the inspecting authority.

8.5.6 One all-weld metal tensile test specimen when the plate thickness is between 10 and 70 mm inclusive; two test specimens, one above the other, in case where the plate thickness is more than 70 mm. The dimensions of the all-weld metal tensile test specimens shall be those shown in Fig. 7.7. The diameter d_0 shall be the maximum possible consistent with the cross section of the weld (*see* IS : 1608-1960*). The gauge length shall be equal to five times the diameter.

8.5.6.1 The result of the test shall meet the requirements given in **8.6.6**.

8.5.7 The dimensions of the reduced-section tensile test specimen shall be those shown in Fig. 8.4A . The width of the reduced section shall be equal to thickness of the plate or 25 mm minimum. The thickness of the specimen shall be equal to the plate thickness and the plate surfaces of the specimen shall be machined to take away the surface irregularities of the plate and the weld. The shape and dimensions of the specimen shall be in accordance with Fig. 8.4 and Table 8.1. If the plate thickness exceeds 30 mm, the tensile test may be effected on several reduced-section specimens, each having a thickness of at least 30 mm and a width at the effective cross section of at least 25 mm. These specimens shall be taken out of the test piece in such a way that the tensile test covers the whole thickness of the welded joint, as shown in Fig. 8.4 (*see also* IS : 1608-1960*).

TABLE 8.1 DIMENSIONS OF REDUCED SECTION TENSILE TEST SPECIMEN

WIDTH $b \pm 0{\cdot}25$ mm	GAUGE* LENGTH G mm	MINIMUM PARALLEL LENGTH P mm	MINIMUM RADIUS AT SHOULDER R mm	APPROXIMATE TOTAL LENGTH L mm
Plate thickness with minimum 25 mm	50	60	50	200
	100	125	50	300
	200	250	50	375

*G, *Min* $= W + 12$ mm.

8.5.7.1 The result of every test specimen concerned shall meet the requirements mentioned under **8.6.1**.

8.5.8 *Impact Test Specimens* — The notched bar impact test specimens are to be one of the two types and dimensions shown in Fig. 8.5 and Fig. 8.6. The notch is to be contained in the weld metal at approximately the axis of the weld and the axis of the notch is to be perpendicular to the surface of the plate (*see* IS : 1757-1961*). The notches should be located according to orientation 'A' and 'B' of Fig. 8.6A and 8.6B, as agreed to between the purchaser and the manufacturer. Orientation 'A' shown in Fig. 8.6A is suitable for use with 10 mm square and sub-standard size specimens. Orientation 'B' is suitable for use with 10 mm square specimens only. In the case of vessels for low temperature operation, impact test specimen shall also be taken from the heat affected zone.

8.5.8.1 In case of plate thickness less than 10 mm, a test specimen similar to that shown in Fig. 8.6A shall be used except that the

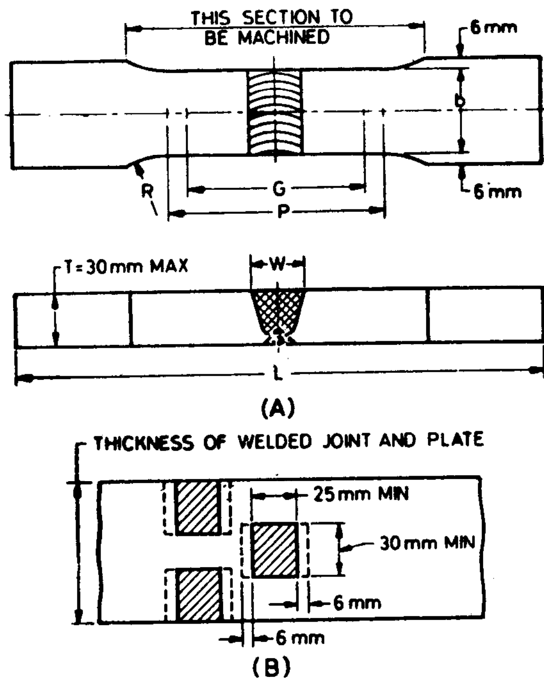
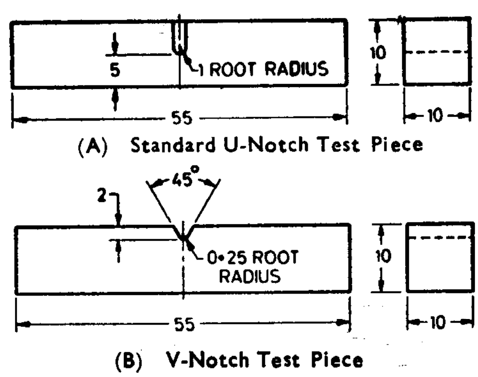


FIG. 8.4 REDUCED-SECTION TENSILE TEST SPECIMEN



All dimensions in millimetres.

FIG. 8.5 IMPACT TEST SPECIMENS

*Method for tensile testing of steel products other than sheet, strip, wire and tube.

*Method for beam impact test (V-notch) on steel.

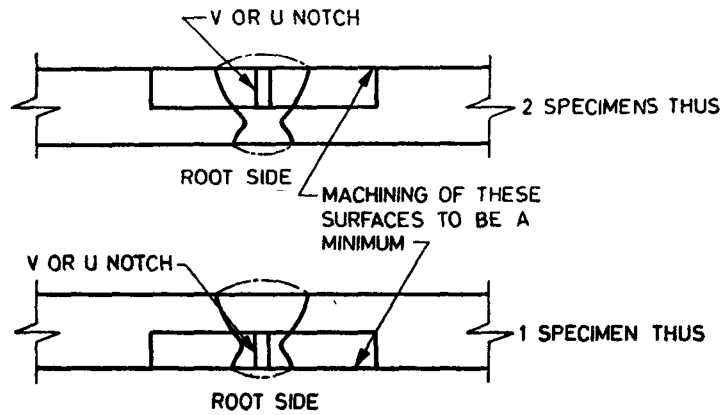


FIG. 8.6A V- OR U-NOTCH CHARPY TEST SPECIMEN SHOWING POSITION OF NOTCH, ORIENTATION A

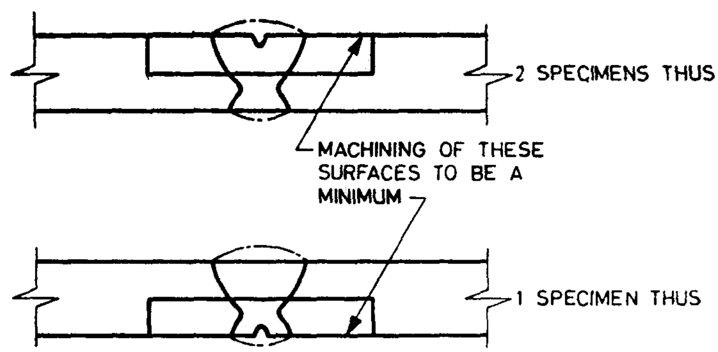


FIG. 8.6B V- OR U-NOTCH CHARPY TEST SPECIMEN SHOWING POSITION OF NOTCH, ORIENTATION B

dimensions along the axis of the notch shall be reduced to the largest possible of 7·5 mm, 5 mm or 2·5 mm.

8.5.8.2 The tests shall be carried out at a temperature within ±2°C of the lowest design metal temperature with a maximum of 50°C.

In the case of the V-notch specimens, the machining of the bottom of the notch shall be done very carefully.

The choice between U-notch and V-notch specimens shall be agreed to between the manufacturer and the inspecting authority. Once the choice is made, it is not allowed to change the type of specimens, even when the test results prove to be unsatisfactory.

8.5.8.3 The result of every test shall meet the requirements mentioned under **8.6.2**.

8.5.9 *Bend Test Specimens*

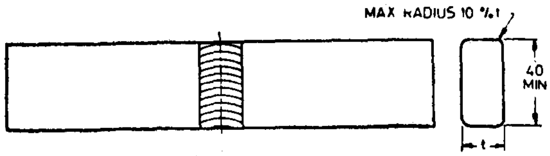
8.5.9.1 The face and root bend test specimens shall be rectangular in section so as to have a width equal to 1½ times the thickness of the specimen subject to a minimum width of 30 mm. The surfaces of the specimen shall be machined or dressed just to remove the surface irregularities of the plate and weld. The corners of the specimens shall be rounded to a radius not exceeding 10 percent of the thickness of the specimen. The length of the specimen shall be such that it satisfies the test requirements.

8.5.9.2 Where the plate thickness does not exceed 30 mm, the thickness of the face and root bend specimens shall be equal to the thickness of the test plate.

8.5.9.3 Where the plate thickness exceeds 30 mm either the face and root bend specimen is maintained at 30 mm or two or more specimens of uniform thickness over their entire length may be cut to represent the full thickness of the joint provided the specimen thickness is not less than 15 mm and not greater than 30 mm (*see* Fig. 8.7A, B and C).

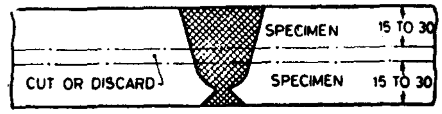
8.5.9.4 The width of the side bend test specimen *b* (*see* Fig. 8.7D) shall be the full thickness of the plate at the weld and the surfaces of the specimen shall be machined or dressed just to remove the surface irregularities of the plate and weld. When the plate thickness is over 40 mm, two or more specimens of equal width may be cut from across the plate thickness provided the specimens' width is not less than 20 mm and not greater than 40 mm. The length of the specimen shall be such that it satisfies the test requirements.

8.5.9.5 Bend test specimens shall be mounted on roller supports (*see* Fig. 8.7C and E) and shall be pushed through the support with a former.



All dimensions in millimetres.

FIG. 8.7A TRANSVERSE FACE AND ROOT BEND SPECIMEN



All dimensions in millimetres.

FIG. 8.7B METHOD OF CUTTING TRANSVERSE BEND TEST SPECIMENS FROM ACROSS FULL PLATE THICKNESS

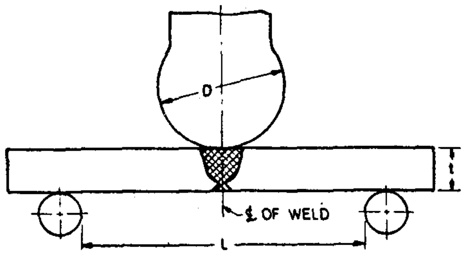
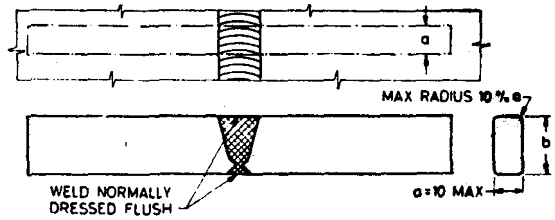


FIG. 8.7C METHOD OF TESTING TRANSVERSE BEND TEST SPECIMEN (*see* TABLE 8.2)



All dimensions in millimetres.

FIG. 8.7D SIDE BEND TEST SPECIMEN

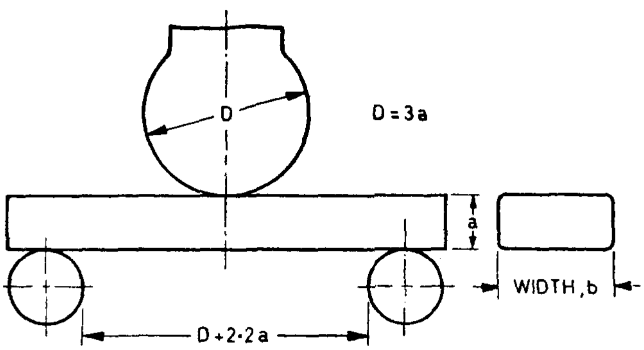


FIG. 8.7E METHOD OF TESTING SIDE BEND SPECIMENS

If the test piece has been reduced in thickness as permitted in **8.5.9.3**, the machined surface shall be in compression. The side of the specimen turned towards the gap between the supports shall be the face for face bend specimens, the root for root bend specimens and the side with the greater defects, if any, for side bend specimens. The distance between roller supports and diameter of the former shall be as given in Table 8.2. The test specimen shall be bent through an angle of 180°. The tests shall be conducted in accordance with IS : 1599-1960*.

8.5.9.6 In the case of austenitic chromium-nickel steel vessels, the specimen shall be ground and polished and immersed for not less than 72 hours in a boiling solution consisting of 47 ml concentrated sulphuric acid and 13 g of crystalline copper sulphate ($CuSO_4$, $5H_2O$) per litre of water. The specimen shall then be bent as laid down under **8.6.3.1**.

8.5.9.7 The result of every test specimen concerned has to meet the applicable requirements mentioned under **8.6.3** or **8.6.3.1**.

*Method for bend test for steel products other than sheet, strip, wire and tube.

TABLE 8.2 DIAMETER OF FORMER AND DISTANCE BETWEEN SUPPORTS

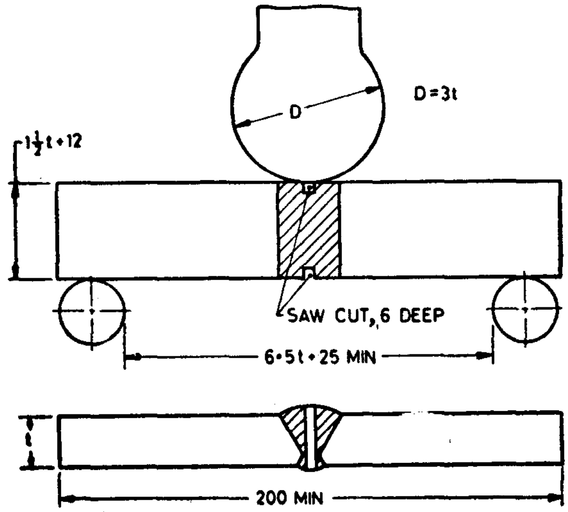
(*Clause* 8.5.9.5)

TENSILE STRENGTH OF PLATE	DIAMETER OF FORMER D	FREE SPACE BETWEEN SUPPORTS AT THE END OF TEST, *Max*
Below 44 kgf/mm^2	2 t	4·2 t
From 44 to 54 kgf/mm^2	3 t	5·2 t
Above 54 kgf/mm^2	4 t	6·2 t

t = the thickness of the plate.

8.5.10 The nick break test specimen shall be of rectangular section as shown in Fig. 8.8. Where the plate thickness does not exceed 30 mm, the thickness of the specimen shall be equal to the full thickness of the plate. Where the plate thickness exceeds 30 mm, the specimen shall in all cases have a thickness of at least 30 mm.

8.5.10.1 The nick break test piece shall be suitably supported so that the notch is at the centre of fusion surface of the test specimen and shall be broken by means of a former or by a blow or blows.



All dimensions in millimetres.

FIG. 8.8 NICK BREAK TEST PIECE

8.5.10.2 The result of every test specimen shall meet the requirements mentioned under **8.6.4**.

8.5.11 *Macro Test Specimen* — The specimen shall be the full thickness of the plate at the weld joint and the excess weld metal and penetration bead shall be left intact. The shape and dimensions of the specimen shall be in accordance with Fig. 8.9. The specimen shall be prepared, polished and etched using an approved method (*see* Appendix K). Material cut from this specimen may be used for micro examination, where necessary.

8.5.11.1 The result of the test shall meet the requirement of **8.6.5**.

8.6 Requirements for Test Results of Welded Production Test Plates

8.6.1 *Reduced-Section Tensile Tests* — The tensile strength obtained shall be at least equal to the specified minimum tensile strength of the base material.

8.6.2 The minimum average results to be obtained from the impact test pieces shown in Fig. 8.9 A and B shall be as follows:

U-notch specimen	5·5 kgf m/cm^2
V-notch specimen	3·5 kgf m/cm^2

NOTE — The values are equivalent to 2·8 kgf m for a 10 × 10 mm test piece.

8.6.3 *Bend Test* — On completion of the test, the specimen shall have no cracks or other open defects exceeding 3 mm measured in any direction on the convex surface of the specimen. Premature failure at the corners of the specimen shall not be considered as a cause for rejection unless there is definite evidence that they result from slag inclusions or other internal defects.

8.6.3.1 The specimens of austenitic chromium-nickel steel plates when bent through the jig for guided-bend test (*see* Fig. 8.10) to produce an

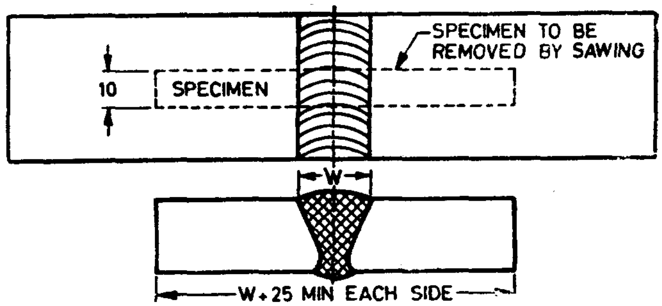


FIG. 8.9 TEST SPECIMEN FOR MACRO EXAMINATION

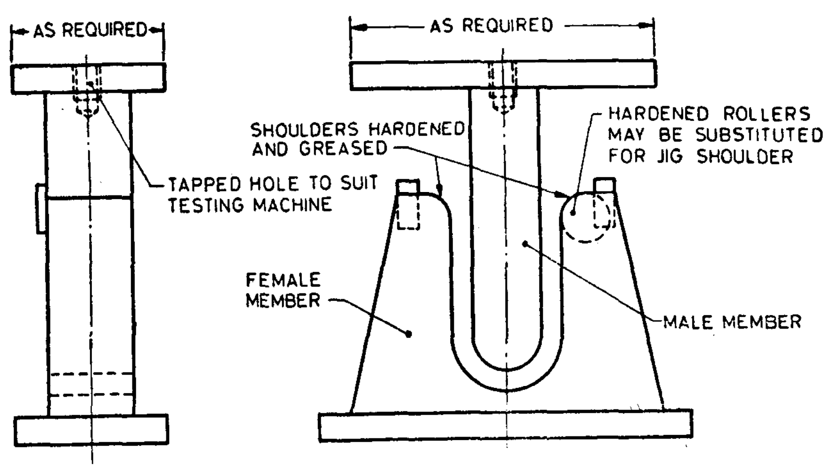


FIG. 8.10 JIG FOR GUIDED-BEND TEST

elongation of not less than 20 percent at the section in the base metal 6 mm from the edge of the weld, shall show no sign of disintegration after bending.

8.6.4 *Nick Break Test* — The fracture on inspection shall show complete penetration throughout the entire thickness of the plate, absence of oxide or slag inclusions and freedom from excessive porosity.

8.6.5 *Macro Test* — The macro-etching of a complete cross section of the weld shall show a good penetration and absence of lack of fusion, significant inclusions and other defects. In case of doubt, the doubtful zone shall be investigated by micro-etching.

8.6.6 *All-Weld Metal Tensile Test* — The tensile strength R obtained shall be at least equal to the specified minimum tensile strength of the base material. The elongation A in percent obtained shall be at least equal to that given by the following equation, in the case of carbon and carbon manganese steels:

$$A = \frac{100 - R}{2{\cdot}2}$$

R being measured in kgf/mm^2.

In addition, this elongation shall not be less than 80 percent of the equivalent elongation given for the base material.

8.6.7 *Radiographs* — The radiographs shall conform to the provisions in **8.7**.

8.6.8 If the results of a test on welded production test plates are unsatisfactory, the causes shall be investigated making use in particular of the results of new tests. If the unsatisfactory results of the original tests are proved to have been caused by local or accidental defects, the results of the retests shall be decisive.

8.6.8.1 *Retests* — Should any of the test pieces fail to meet the specified requirements, retests shall be allowed for each test piece that fails, as follows:

a) *Tensile tests* — Where any result of the tensile tests is not less than 95 percent of the specified value one retest shall be made. Where the result falls below 95 percent, two retests shall be made.

b) *Bend tests* — Where a bend or nick break test piece fails to meet the specified requirements, two retests shall be made.

c) *Notched bar impact tests* — If a notched bar test fails to meet the specified requirements, two retests shall be made, on test pieces taken from the test plate, one on each side of the original specimen and separated from it by not more than 5 mm.

8.6.8.2 Should any of the retests fail to meet the specified requirements, the welded seams represented by these tests shall be deemed not to comply with this standard.

8.7 Non-destructive Examination and Repairs of Welded Seams

8.7.0 For general guidance in radiographic technique, reference may be made to IS : 2595-1963*.

8.7.1 *Radiography A* — It covers the radiographic examination of all longitudinal and circumferential butt welds in drums, shells and headers throughout their whole length including points of intersection with other joints.

8.7.1.1 For circumferential butt welds in extruded connections, pipes, tubes, headers and other tubular parts:

a) no radiographic examination is required where the thickness does not exceed 6 mm;

b) no radiographic examination is required where the thickness is greater than 6 mm but does not exceed 12 mm and the outside diameter does not exceed 102 mm;

c) in constructions where the thickness and outside diameter are greater than those specified in (a) and (b) above, but do not exceed 20 mm or 170 mm respectively, five welds selected at random from each welder's work, but with a maximum of 5 percent of the total length of welds, shall be radiographically examined; and

d) for constructions exceeding the limits specified in (c) above, all the welded joints shall be radiographically examined. Figure 8.11 clarifies graphically the requirements as formulated under (a), (b), (c) and (d).

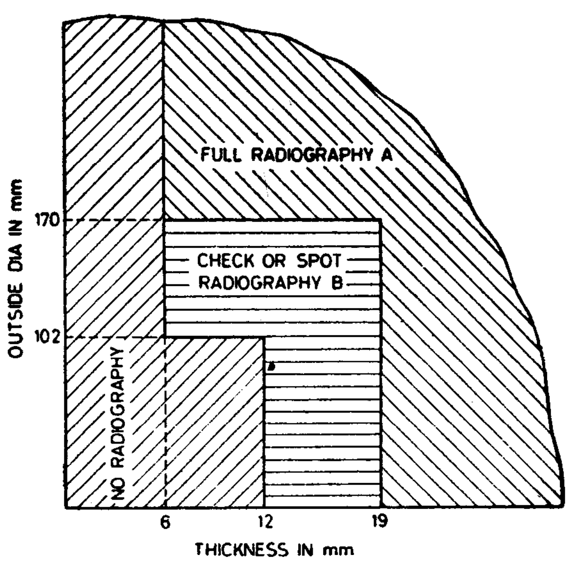


Fig. 8.11 Radiographic Examination

8.7.1.2 Butt welds in furnaces, combustion chambers and other pressure parts under external pressure, are subject to check radiographic examination. Butt welds in fully supported end plates are not subject to radiographic examination.

*Code of practice for radiographic testing.

8.7.2 *Radiography B* — Spot or check radiographic examination of the welded joints in question, comprising at least 10 percent of their whole length. The individual radiographs should not be shorter than 25 cm unless this is necessitated by the shape of the joints, the radiographic examination shall in all cases comprise all points of intersection with other joints, unless these points have already been examined by the radiographic examination of the other joints. At least one radiograph for the work of each welder or welding operator used in the fabrication of the vessel is necessary.

8.7.2.1 If the results of the examination of check radiographs of the selected welds are not satisfactory, the cause shall be investigated and, if considered necessary, the percentage of radiographic inspection increased by agreement between the manufacturer and the inspecting authority.

8.7.3 *Preparation of Welds for Radiographic Examination* — All butt welded joints to be radiographed shall be free from weld ripples or weld surface irregularities on both the inside and the outside, to a degree such that the resulting radiographic contrast due to any remaining irregularities cannot be confused with that of any objectionable defects. Also the weld surface shall merge smoothly into the plate surface.

8.7.3.1 The finished surface of reinforcement may be flush or have a reasonably uniform crown not exceeding the limits stipulated in **6.7.16**.

8.7.3.2 Welded butt joints of the 'backing strip' (*see* Table 6.1) type may be radiographed without removing the backing strip provided that the image of the latter is not significantly detrimental to the interpretation of the radiographs.

8.7.3.3 Radiographic examination should be conducted before final heat treatment.

8.7.4 *Penetrameters* — To check the image quality of the radiographs, use shall be made of either a wire type or stepwedge type (*see* IS : 3657-1966*) image quality indicator or penetrameter. At least two penetrameters shall be used for each radiograph. One penetrameter shall be placed at each end of the length of weld shown on each radiograph. Further, the penetrameters shall be placed on the source side and not on the film side. The radiographic examination shall be capable of revealing a difference in metal thickness equal to not more than 2 percent of the thickness of weld under examination.

8.7.4.1 The penetrameter should be placed parallel with and close to the weld with the wire or hole which is the smallest in diameter positioned away from the centre of the length of weld under examination. Each section of the weld shall be marked so that the radiographs can easily be correlated to the particular part of the joint represented.

*Specification for radiographic image quality indicators.

In the case of welds with reinforcement a shim may be provided, the thickness of which conforms to the sum of the mean thickness of the weld reinforcements passed by the radiation.

When the penetrameter is placed adjacent to the weld seam and the weld reinforcement and/or backing strip is not removed, a shim of the same material as backing strip shall be placed under the penetrameter such that the total thickness being radiographed under the penetrameter is the same as the total thickness through the weld, including backing strip when used and not removed.

8.7.5 *Interpretation of Radiographs* — The examination of radiographs of welds shall be made on the original films, using a viewing device of suitable illuminating power.

8.7.5.1 For correct interpretation of radiograph, the film density shall preferably be between 2 and 3 but in no case less than 1·7 (*see* IS : 1182-1967* and IS : 4853-1968†).

8.7.5.2 The following standard of acceptance applies to radiographs of butt welds in drums and shells and longitudinal butt welds in headers, but not to circumferential butt welds in headers, pipes and tubes. The root runs of circumferential welds in headers, pipes and tubes shall be substantially free from defects.

8.7.5.3 Butt welds in drums and shells and longitudinal butt welds in headers shall in no case be acceptable, if having one or more of the following defects:

Radiography A

a) Cracks or areas having incomplete fusion or penetration;

b) Any elongated inclusion of a length exceeding:

   1) half the thickness with a maximum of 6 mm for thickness not exceeding 18 mm,

   2) one-third the thickness for thicknesses over 18 mm and up to and including 75 mm, and

   3) 25 mm for thicknesses exceeding 75 mm;

c) Any group of inclusions of slag in alignment, the total length of which exceeds the thickness over a length of 12 times the thickness except when the distance between successive defects exceeds 6 times the length of the longest defect in the group; and

d) Any porosity greater than that given in Fig. 8.12A to E.

*Recommended practice for radiographic examination of fusion welded butt joints in steel plates (*first revision*).

†Recommended practice for radiographic examination of fusion welded circumferential joints in steel pipes.

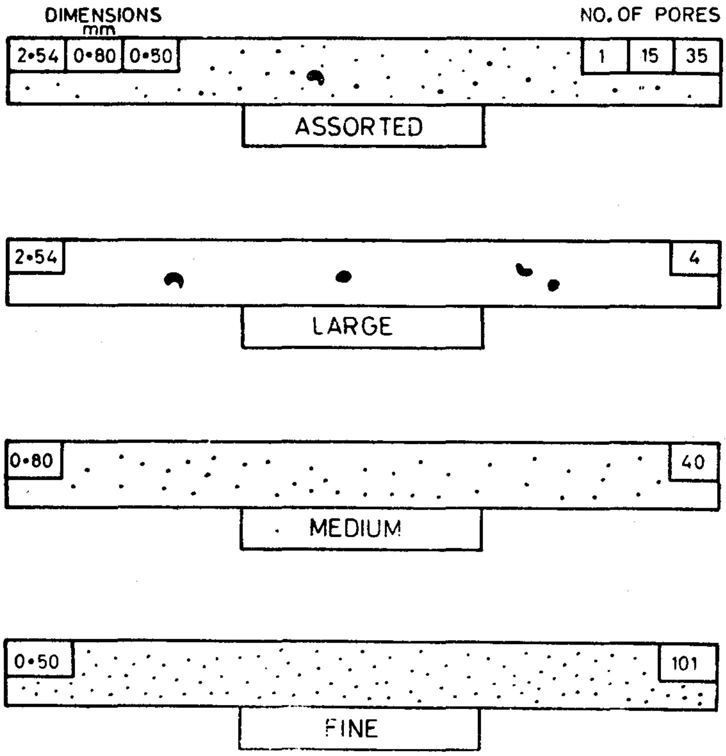


Fig. 8.12A Porosity Chart, Plate 6·5 mm or Less

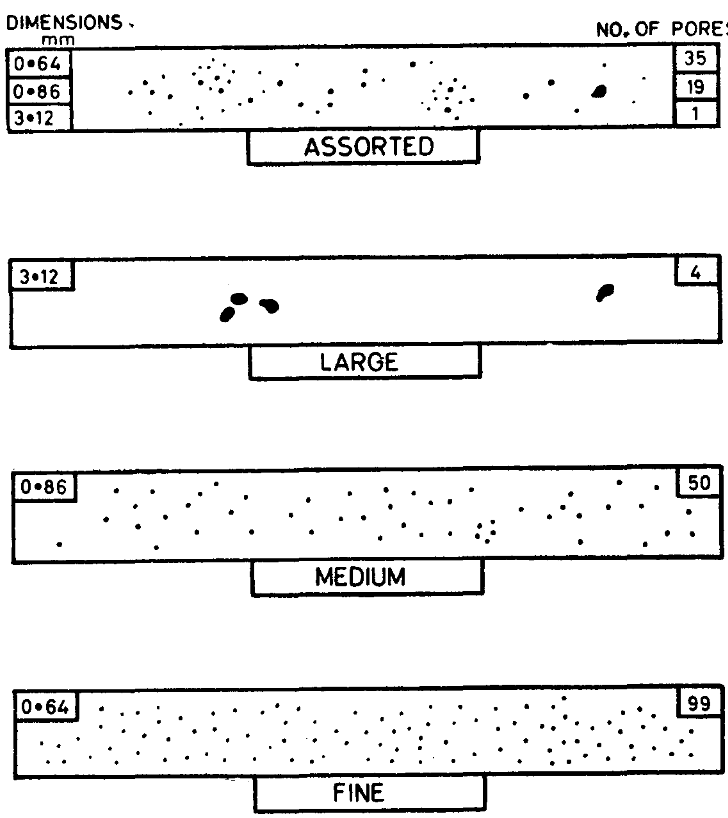


Fig. 8.12B Porosity Chart, Plate over 6·5 mm to 12 mm

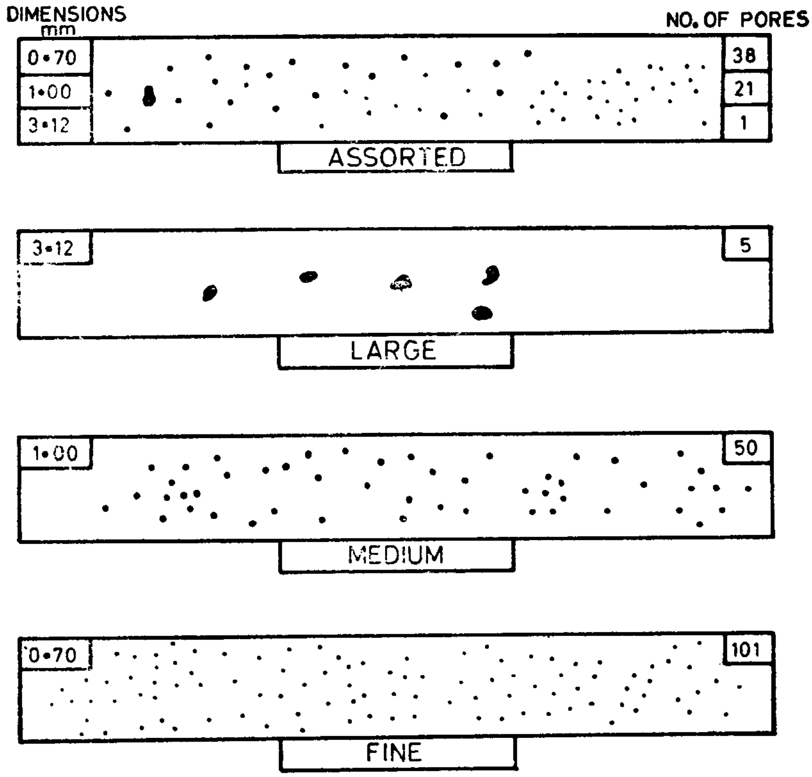


FIG. 8.12C POROSITY CHART, PLATE OVER 12 mm TO 32 mm

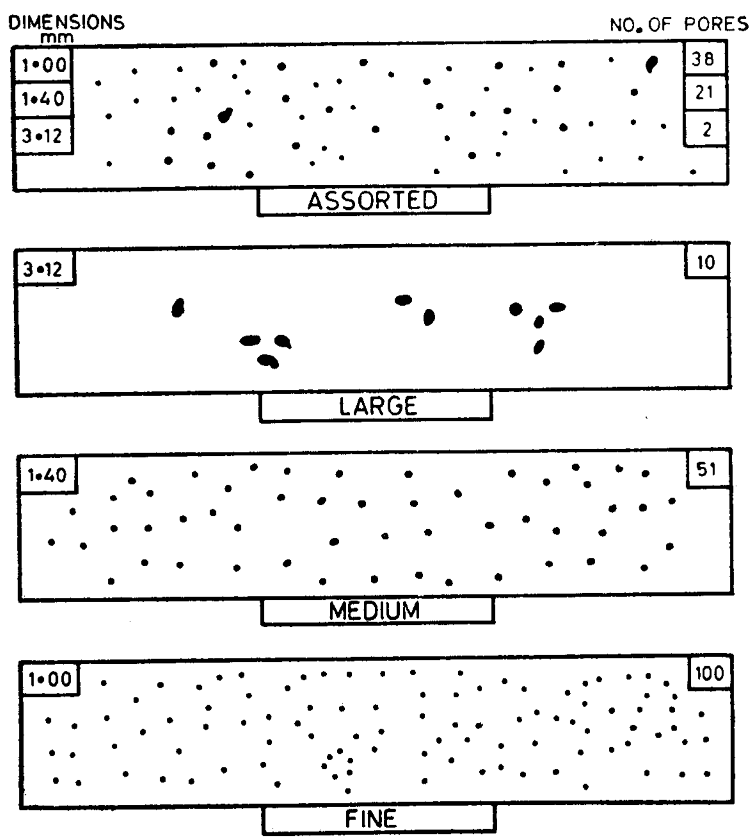


FIG. 8.12D POROSITY CHART, PLATE OVER 32 mm TO 64 mm

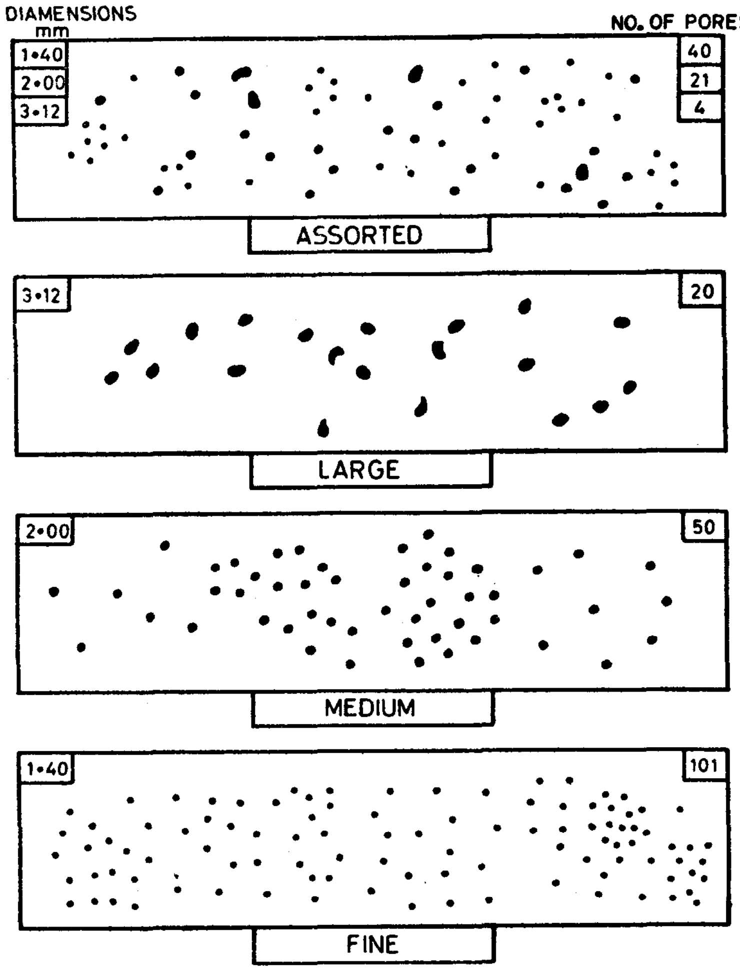


FIG. 8.12E POROSITY CHART, PLATE OVER 64 mm

Radiography B

a) Cracks or areas having incomplete fusion or penetration;

b) Any inclusion or cavities of a length exceeding two-thirds of the thickness of thinner plate welded;

c) Any group of inclusions in alignment, the total length of which exceeds the thickness over a length of six times the thickness, except when the distance between the successive defects exceeds three times the length of the longest defect in the group. The maximum length of elongated inclusions permitted shall not be more than 12 mm; and

d) Porosity is not a factor in the acceptability of welds not required to be fully radiographed.

8.7.5.4 Alternative to the provision of **8.7.5.3**, the radiographs may be interpreted with regard to the quality of the welded joints according to the marking scale indicated below ranging from 5 to 1, where 5 is the highest and 1 is the lowest obtainable mark. As a basis for the interpretation, the X-ray 'IIW Collection of Reference Radiographs of Welds', Atlas issued by the International Institute of Welding shall be used.

Marks	*IIW Colour*	*The Radiograph Shows*
5	Black	A homogeneous weld or a weld with a few small scattered gas cavities
4	Blue	Very slight deviations from homogeneity in the form of one or more of the following defects, namely: (a) gas cavities, (b) slag inclusions, and (c) undercut
3	Green	Slight deviations from homogeneity in the form of one or more of the following defects, namely: (a) gas cavities, (b) slag inclusions, (c) undercut, (d) incomplete penetration, and (e) lack of fusion

Marks	*IIW Colour*	*The Radiograph Shows*
2	Brown	Marked deviations from homogeneity in the form of one or more of the following defects, namely: (a) gas cavities, (b) slag inclusions, (c) undercut, (d) incomplete penetration, and (e) lack of fusion
1	Red	Gross deviations from homogeneity in the form of one or more of the following defects, namely: (a) gas cavities, (b) slag inclusions, (c) undercut, (d) incomplete penetration, (e) lack of fusion, and (f) cracks

Welded joints in pressure vessels which are required to be made in accordance with this code shall obtain a minimum of 4 marks in the radiographic examination.

Isolated films getting lower marks may, however, be accepted with the permission of the inspecting authority in each individual case.

8.7.6 Any repair to a weld carried out by the manufacturer shall be reported to the inspecting authority. If the repair is made as a consequence of a radiographic examination, the films of the original defects and after repiar of defects, shall be made available to the inspecting authority. If the defects form a continuous line, the extent of repair shall be agreed upon between the manufacturer and the inspecting authority.

8.7.7 If a longitudinal seam fails to meet the requirements of the code and it is desired to effect a repair by removing the whole weld and rewelding it, the original test plate shall be cut and repaired to simulate condition of main seam weld. If it is not possible, a new production plate shall be provided.

8.7.8 If a circumferential seam fails to meet the requirements of the code and it is desired to effect a repair by removing the whole weld and rewelding it, the inspecting authority shall be entitled to call for a new production plate, if required.

8.7.9 All repaired areas shall be subject to radiographic examination where radiography was originally required.

8.7.10 *Radiographic Examination*

8.7.10.1 *Identification of radiographs*

a) Numerals shall be stamped on the vessel alongside the welded seams so that each radiograph may be identified with the portion of seam represented. The stamped impression shall be of a suitable radius; a stamp which produces a sharp-edged notch in the plate shall not be used. Where identification marks stamped on vessels are not deep enough to be radiographed, such markings may be radiographed with lead numerals or markers placed over them, with the previous consent of the inspecting authority.

b) Where radiographs are required of the entire length of a welded seam, sufficient overlap shall be provided to ensure that the radiographs cover the whole of the welded seam, and each radiograph shall exhibit a number near each end (*see* Fig. 8.13).

c) Lead numerals shall be placed on the opposite side of the weld to the appropriate stamped numerals to provide ready identification of the radiographs with the portion of welded seam represented (*see* Fig. 8.13).

d) The width of the weld shall be indicated by suitable lead pointers placed on each side of, and clear of, the outside edges of the weld. Alternatively, lead wires of small diameter, placed on each side of the weld and clear of, but not more than 3 mm from the outside edges of the weld, may be employed.

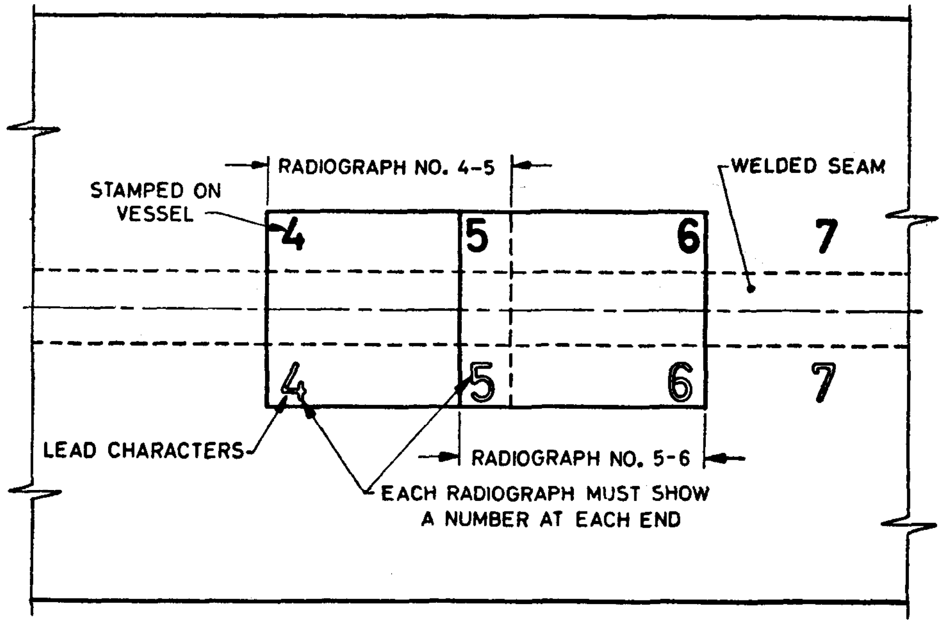
e) Lead characters shall be placed alongside the weld to provide the following information on the individual radiographs:

   1) The region of the welded seam covered by the radiograph.

   2) The location of the welded seam using a letter *L* for a longitudinal seam and *C* for a circumferential seam with the addition of a numeral (1, 2, 3, etc) to indicate whether the seam was the first, second, or third, etc, of the type. Thus the second circumferential seam in a vessel would be marked 2*C* as shown in Fig. 8.14 (*see* notes on Appendix L).

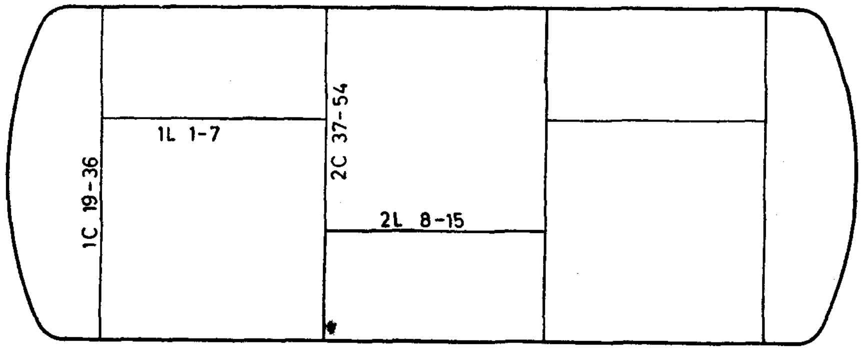
      Where the welded seam under examination is contained in the jacket of a vessel, it is recommended that the letter *J* should be prefixed to the lead characters denoting the location of the welded seam, for example, *JL* would represent the second longitudinal seam of the jacket.

   3) For the particular vessel to which the radiographs apply, this identification could be provided by lead characters which indicate information, such as the works serial number, the order number or similar references. The result of the radiographic examination shall be detailed on a report form (*see* Appendix L) signed by the approved person responsible for the inspection. The report should be accompanied by a drawing or diagram showing the exact location of defects.



Sufficient overlap is to be provided on the radiographs to ensure that the whole of the welded seam is covered.

FIG. 8.13 MARKING FOR IDENTIFICATION OF RADIOGRAPHS



The length between numbers for the longitudinal seam is.........mm.
The length between numbers for the circumferential seam is.........mm.

FIG. 8.14 SKETCH OF VESSEL SHOWING FILM LOCATION

8.7.10.2 *Testing technique* — The radiographic technique shall be capable of detecting difference in metal thickness of at least 2 percent of the thickness of the plate under examination, and this shall be clearly indicated on each individual radiograph by means of an adequate indicator radiographed on to the films.

The width of the radiographs shall be at least equal to the total width of the welded joints plus an allowance of about 10 mm on each side of the welded joint.

8.7.10.3 *Re-examination of repaired joints*

a) Welded joints or parts thereof, which do not show the quality required, shall be repaired, *see* **6.9**).

After such repairs the parts in question of the welded joints shall be subjected to renewed radiographic examination, and shall meet the requirements of **8.7.5.3** and **8.7.5.4.**

b) If any part of a welded joint, which has been subjected to Radiography B, or which has been examined at the points of intersection with other joints does not show the quality required, an additional radiographic examination shall be carried out in the following manner.

On each side of and in immediate extension of that part of the welded joint, where the radiograph was previously located, one additional radiograph shall be made. These radiographs should be not shorter than 250 mm, unless this is necessitated by the shape of the joint. If the first radiograph

has been made at a point of intersection and of a welded joint ending in this point, only one radiograph is to be made in extension of the first one.

Should special conditions make it expedient, the inspecting authority has the right to modify the location of such additional radiographs.

c) Should the two additional radiographs made in accordance with (b) above meet the quality requirements, the entire weld unit represented by the three radiographs is acceptable. The defective welding disclosed by the first of the three radiographs may be removed and the area repaired by welding or it may be allowed to remain there at the discretion of the inspecting authority.

d) Should any of the additional radiographs made in accordance with (b) above do not meet the quality requirements of **8.7.5.3** or **8.7.5.4**, the entire unit of weld shall be rejected and the joint in question shall be radiographed throughout its entire length and shall be repaired where necessary, followed by a renewed examination of all repaired parts of the joint.

In addition to this, a further random radiographic examination shall be carried out on the other joints of the vessel in question, unless these joints have already been examined throughout their entire length. This additional examination shall comprise the same number of radiographs as prescribed for Radiography B. Should any of these additional radiographs fail to meet the requirements of **8.7.5.3** or **8.7.5.4**, the joint in question shall be examined throughout its entire length and shall be repaired where necessary, followed by renewed examination, until the quality requirements have been met with.

Should the random radiographic examination of a vessel reveal a larger number of systematic defects of such character that similar defects may be expected to occur to a greater or smaller extent in the welds as a whole, or in all welds of a certain category, the inspecting authority has the right to request an extension of the examination including a complete examination of all welds, or including all welds in the vessel within the category in question.

All parts of the welded joints, which do not meet the requirements stated under **8.7.5.3** or **8.7.5.4** shall be repaired and re-examined after repair.

e) No repairs shall be carried out after the radiographic examination without the prior consent of the inspecting authority.

f) Radiographic films shall be preserved by the manufacturer for a period of at least five years after the acceptance of the films.

8.7.10.4 *Protection of personnel* — All persons exposed to X or gamma rays and engaged in radiographic work shall be suitably shielded against direct and scattered radiations.

For detailed information, reference may be made to IS : 2598-1966*.

8.7.11 *Other Non-destructive Testing Methods* — When special conditions make it expedient, radiography as specified in **8.7.1** and **8.7.2** may be replaced by other non-destructive testing methods, for example, dye penetrant, magnetic or ultrasonic testing methods upon previous consent of the inspecting authority, and on the condition that such testing methods may be considered to render an equally safe evaluation of the quality of the welding work. Such non-destructive testing methods may also be employed to ascertain the quality of welds, where radiography cannot be easily employed as in the case of fillet and butt welds on branches and fittings.

See IS : 3664-1966†, IS : 4260-1967‡, IS : 3658-1966§ and IS : 3703-1966||.

9. MARKING AND RECORDS

9.0 All vessels built under this code shall conform to the provisions of this code in every detail and shall be distinctly stamped and certified.

9.1 Marking — Each pressure vessel shall have stamped upon its front plate in a conspicuous position the following particulars:

Manufacturer's name

Manufacturer's serial No.

Year built

Max W.P..................at Temp................°C

IS : 2825..................FR¶/PR**/SR††

Hydraulic pneumatic test pressure..................

Date of test............

Inspecting authority's official stamp

9.1.1 The figures and letters of the stamping shall be at least 8 mm high when stamped directly on the vessel or 4 mm high when stamped on a permanently attached name-plate. The figures and letters shall be legible and stamped fully into the plate. Deep stamping shall be avoided when stamped directly on the vessel.

9.1.2 Stamping of vessels may be made directly on the vessel or may be stamped on a permanently attached name-plate so fixed as not to be covered by lagging or insulation. Permanently attached name-plates shall be used on all vessels of steel plate less than 7 mm thick.

*Safety code for industrial radiographic practice.

†Code of practice for ultrasonic testing by pulse echo method (direct contact).

‡Recommended practice for ultrasonic testing of welds in ferritic steel.

§Code of practice for liquid penetrant flaw detection.

||Code of practice for magnetic flaw detection.

¶FR, if fully radiographed (Radiography A).

**PR, if spot or check radiographed (Radiography B).

††SR, if stress-relieved.

9.1.3 The stamping area shall be painted and outlined in a contrasting colour. The stamping or name-plate described in **9.1** and **9.1.2**, shall be kept free of any covering.

9.1.4 Either of the following arrangements may be used in marking vessels having two or more independent pressure chambers designed for the same or different operating conditions. Each detachable chamber shall be marked so as to identify it positively with the combined unit:

a) The marking may be grouped in one location on the vessel, provided it is arranged so as to indicate clearly the data applicable to each chamber.

b) The complete required marking may be applied to each independent pressure chamber, provided additional marking, such as stock space, jacket, tube-nest or channel box is used to indicate clearly to which chamber the data apply.

9.1.4.1 Removable pressure parts shall be permanently marked in a manner to identify them with the vessel or chamber of which they form a part. This does not apply to manhole covers, handhole covers, etc.

9.2 Certificate of Manufacture and Test — A certificate of manufacture and test in form is given in Appendix M shall be filled out by the manufacturer and signed by the manufacturer or a responsible representative of the manufacturer and shall be complete with all the enclosure referred to in form in Appendix M. The manufacturer shall issue such a certificate for every vessel fabricated by him.

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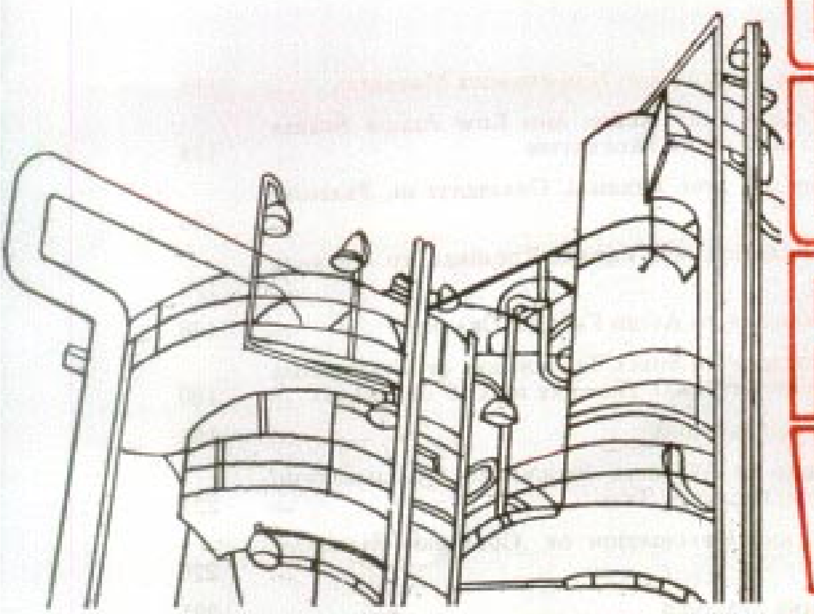
IS : 2825-1969

APPENDICES

CODE FOR UNFIRED PRESSURE VESSELS



APPENDIX A TO APPENDIX N

APPENDICES

APPENDIX A

(*Clause* 2.2.1.1)

ALLOWABLE STRESS VALUES FOR FERROUS AND NON-FERROUS MATERIAL

A-1. STRESS VALUES

A-1.1 The allowable stress values for carbon and low alloy steels are given in Table A.1 as determined from the criteria given in Table 2.1 and Appendix B.

TABLE A.1 ALLOWABLE STRESS VALUES FOR CARBON AND LOW ALLOY STEEL IN TENSION

Material Specification	Grade or Designation	Mechanical Properties			Allowable Stress Values in kgf/mm² at Design Temperature °C												
		Tensile Strength *Min* kgf/mm² R_{20}	Yield Stress *Min* kgf/mm² E_{20}	Percentage Elongation *Min* on Gauge Length $=5{\cdot}65\sqrt{S_o}$	Up to 250	Up to 300	Up to 350	Up to 375	Up to 400	Up to 425	Up to 450	Up to 475	Up to 500	Up to 525	Up to 550	Up to 575	Up to 600
				Plates													
IS : 2002-1962	I	37	0·55 R_{20}	26	9·5	8·7	7·8	7·5	7·2	5·9	4·3	3·6	—	—	—	—	—
IS : 2002-1962	2A	42	0·50 R_{20}	25	9·8	9·0	8·1	7·7	7·4	5·9	4·3	3·6	—	—	—	—	—
IS : 2002-1962	2B	52	0·50 R_{20}	20	12·1	11·1	10·0	9·5	8·3	5·9	4·3	3·6	—	—	—	—	—
IS : 2041-1962	20Mo55	48	28	20	14·3	13·2	12·3	11·9	11·5	11·2	10·8	7·7	5·6	3·7	—	—	—
IS : 2041-1962	20Mn2	52	30	20	14·0	12·8	11·6	11·0	8·3	5·9	4·3	3·6	—	—	—	—	—
IS : 1570-1961	15Cr90Mo55	50	30	20	16·0	15·2	14·4	13·8	13·4	13·0	12·6	11·7	8·6	5·8	3·5	—	—
IS : 1570-1961	C15Mn75	42	23	25	10·7	9·8	8·9	8·4	8·1	5·9	4·3	3·6	—	—	—	—	—
				Forgings													
IS : 2004-1962	Class 1	37	0·50 R_{20}	—	8·6	7·9	7·1	6·8	6·5	5·9	4·3	3·6	—	—	—	—	—
IS : 2004-1962	Class 2	44	0·50 R_{20}	15	10·2	9·3	8·5	8·0	7·7	5·9	4·3	3·6	—	—	—	—	—
IS : 2004-1962	Class 3	50	0·50 R_{20}	21	11·7	10·7	9·6	9·1	8·3	5·9	4·3	3·6	—	—	—	—	—
IS : 2004-1962	Class 4	63	0·50 R_{20}	15	14·7	13·4	12·2	11·5	8·3	5·9	4·3	3·6	—	—	—	—	—
IS : 1570-1961	20Mo55	48	28	20	14·3	13·2	12·3	11·9	11·5	11·2	10·8	7·7	5·6	3·7	—	—	—
IS : 2611-1964	15Cr90Mo55	50	30	20	16·0	15·2	14·4	13·8	13·4	13·0	12·6	11·7	8·6	5·8	3·5	—	—
IS : 1570-1961	10Cr2Mo1	50	32	20	17·9	17·3	16·4	16·1	15·8	15·3	14·9	12·7	9·6	7·0	4·9	3·2	2·3

(*Continued*)

TABLE A.1 ALLOWABLE STRESS VALUES FOR CARBON AND LOW ALLOY STEEL IN TENSION — *Contd*

Material Specification	Grade or Designation	Mechanical Properties: Tensile Strength *Min* kgf/mm² R_{20}	Mechanical Properties: Yield Stress *Min* kgf/mm² E_{20}	Mechanical Properties: Percentage Elongation *Min* on Gauge Length $=5{\cdot}65\sqrt{S_0}$	Allowable Stress Values in kgf/mm² at Design Temperature °C: Up to 250	Up to 300	Up to 350	Up to 375	Up to 400	Up to 425	Up to 450	Up to 475	Up to 500	Up to 525	Up to 550	Up to 575	Up to 600
				Tubes, Pipes													
IS : 3609-1966	1% Cr ½% Mo Tube Normalized and Tempered	44	24	$950/R_{20}$	12·8	12·1	11·5	11·1	10·7	10·4	10·0	9·7	8·6	5·8	3·5	—	—
IS : 3609-1966	2¼% Cr 1% Mo Tube Normalized and Tempered	49	25	$950/R_{20}$	14·0	13·5	12·8	12·6	12·3	12·0	11·6	11·3	9·6	7·0	4·9	—	—
IS : 1570-1961	20Mo55	46	25	$950/R_{20}$	12·8	11·8	11·0	10·6	10·3	10·0	9·6	7·7	5·6	3·7	—	—	—
IS : 1914-1961	32 kgf/mm², *Min*, Tensile Strength	32	0·50 R_{20}	$950/R_{20}$	7·4	6·8	6·2	5·8	5·6	5·0	4·3	3·6	—	—	—	—	—
IS : 1914-1961	43 kgf/mm², *Min*, Tensile Strength	43	0·50 R_{20}	$950/R_{20}$	10·0	9·2	8·3	7·9	7·6	5·9	4·3	3·6	—	—	—	—	—
IS : 2416-1963	32 kgf/mm², *Min*, Tensile Strength	32	0·50 R_{20}	$950/R_{20}$	7·4	6·8	6·2	5·8	5·6	5·0	4·3	3·6	—	—	—	—	—
IS : 1978-1961	St 18	31·6	17·6	—	8·2	7·5	6·7	6·4	6·2	5·9	4·3	3·6	—	—	—	—	—
	St 20	33·7	19·7	—	9·2	8·4	7·6	7·2	6·9	5·9	4·3	3·6	—	—	—	—	—
	St 21	33·7	21·1	—	9·8	9·0	8·1	7·7	7·4	5·9	4·3	3·6	—	—	—	—	—
	St 25	42·2	24·6	—	11·5	10·5	9·5	9·0	8·3	5·9	4·3	3·6	—	—	—	—	—
IS : 1979-1961	St 30	42·2	29·5	—	13·8	12·6	11·5	10·8	8·3	5·9	4·3	3·6	—	—	—	—	—
	St 32	44·3	32·3	—	15·0	13·8	12·5	11·8	8·3	5·9	4·3	3·6	—	—	—	—	—
	St 37	46·4	36·6	—	17·1	15·6	14·1	13·4	8·3	5·9	4·3	3·6	—	—	—	—	—

					Castings*												
IS : 3038-1965	Grade 1	55	35	17	12·2	11·2	10·1	9·6	6·2	4·4	3·2	2·7	—	—	—	—	—
	Grade 2	47	25	17	9·6	8·8	8·2	8·0	7·7	7·5	7·2	5·8	4·2	2·8	—	—	—
	Grade 3	52	31	15	11·9	11·0	10·2	9·9	9·6	9·3	8·4	5·8	4·2	2·8	—	—	—
	Grade 4	49	28	17	11·2	10·6	10·1	9·7	9·3	9·1	8·8	8·5	6·5	4·4	2·6	—	—
	Grade 5	52	31	17	13·0	12·5	11·9	11·7	11·4	11·1	10·8	9·5	7·2	5·3	3·7	2·4	—
	Grade 6	63	43	15	17·2	16·3	15·5	14·9	14·4	14·0	13·5	6·7	4·9	3·5	2·6	1·7	0·9
IS : 2856-1964	C Sw-C20	42	21	20	7·3	6·7	6·1	5·7	5·5	4·4	3·2	2·7	1·6	—	—	—	—
	C Sw-C25	49	25	18	8·7	8·0	7·2	6·8	6·2	4·4	3·2	2·7	1·6	—	—	—	—
					Rivet and Stay Bar												
IS : 1990-1962		37	0·55 R_{20}	26	8·6	7·9	7·1	6·8	6·5	5·9	4·3	3·6	—	—	—	—	—
		42	0·55 R_{20}	23	9·8	9·0	8·1	7·9	7·4	5·9	4·3	3·6	—	—	—	—	—
					Sections, Plates, Bars												
IS : 226-1962	St 42-S	42	24	23	9·8	9·0	8·1	—	—	—	—	—	—	—	—	—	—
IS : 961-1962	St 55 HTW	50	29	20	11·7	10·7	9·6	—	—	—	—	—	—	—	—	—	—
IS : 2062-1962	St 42 -W	42	23	23	9·8	9·0	8·1	—	—	—	—	—	—	—	—	—	—
IS : 3039-1965	Grade A	—	—	—	9·8	9·0	8·1	—	—	—	—	—	—	—	—	—	—
	Grade D	—	—	—	11·7	10·7	9·6	—	—	—	—	—	—	—	—	—	—
IS : 3503-1966	Grade 1	37	0·55 R_{20}	26	8·6	7·9	7·1	6·8	6·5	5·9	4·3	3·6	—	—	—	—	—
	Grade 2	42	0·55 R_{20}	25	9·8	9·0	8·1	7·7	7·4	5·9	4·3	3·6	—	—	—	—	—
	Grade 3	44	0·55 R_{20}	23	10·2	9·3	8·5	8·0	7·7	5·9	4·3	3·6	—	—	—	—	—
	Grade 4	47	0·55 R_{20}	22	11·7	10·7	9·6	9·1	8·3	5·9	4·3	3·6	—	—	—	—	—
	Grade 5	50	0·55 R_{20}	21	12·1	11·1	10·0	9·5	8·3	5·9	4·3	3·6	—	—	—	—	—
IS : 3945-1966	Grade A-N	44	24	23	9·8	9·0	8·1	—	—	—	—	—	—	—	—	—	—
	Grade B-N	50	28·5	20	11·7	10·7	9·6	—	—	—	—	—	—	—	—	—	—

*These values have been based on a quality factor of 0·75. For additional inspection as detailed in Note to Table 2.1 a quality factor of 0·9 shall be used and the above stress values increased proportionally.

A-1.2 The allowable stress values for high alloy steels are given in Table A.2.

TABLE A.2 ALLOWABLE STRESS VALUES FOR HIGH ALLOY STEELS IN TENSION

Material Specification	Designation	Product	Remarks	Mechanical Properties			Allowable Stress Values in kgf/mm² at Design Temperature °C							
				Tensile Strength kgf/mm² *Min* R_{20}	Yield Stress kgf/mm² *Min* E_{20}	Elongation Percent *Min* on Gauge Length $5{\cdot}65\sqrt{S_o}$	Up to 50	100	150	200	250	300	350	400
IS : 1570-1961	04Cr19Ni9	Plates, sections, Bars, forgings and seamless tubes	Austenitic stainless steels	55	24	28	16·00	14·20	12·40	10·60	9·97	9·35	8·70	8·07
	04Cr19Ni9Ti20			55	24	28	16·00	14·28	12·56	10·83	10·64	10·60	10·60	10·80
	04Cr19Ni9Nb40			55	24	28	16·00	14·28	12·56	10·83	10·64	10·60	10·60	10·60
	05Cr18Ni11Mo3			55	24	28	16·00	14·50	13·00	11·50	11·24	11·23	11·23	11·12
	05Cr19Ni9Mo3Ti20			55	24	28	16·00	14·50	13·00	11·50	11·24	11·23	11·23	11·12
IS : 3444-1966	Grade 7, 8	*Castings		47	21	21	14·00	12·94	11·88	10·83	10·64	10·60	10·60	10·60
	Grade 9, 11			47	21	13	14·00	13·17	12·34	11·50	11·24	11·23	11·23	11·12

*For castings, values have been based on a quality factor of 0·75. For additional inspection as detailed in Note to Table 2.1, a quality factor of 0·9 shall be used and the above stress values increased accordingly.

A-1.3 Allowable stress values for aluminium and aluminium alloys are given in Table A.3.

TABLE A.3 ALLOWABLE STRESS VALUES FOR ALUMINIUM AND ALUMINIUM ALLOYS IN TENSION

Material	Grade and Products		Condition	Mechanical Properties			Allowable Stress Values in kgf/mm² at Design Temperature °C							Remarks
				Tensile Strength *Min* kgf/mm²	0·2 Proof Stress *Min* kgf/mm²	Elongation on $4\sqrt{S_o}$ *Min* Percent	Up to 50	Up to 75	Up to 100	Up to 125	Up to 150	Up to 175	Up to 200	
IS : 736-1966	PIB	Plate	M	6·5	—	30	1·36	1·27	1·16	1·05	0·95	0·84	0·74	Mechanical properties are those of solution and precipitation heated material
IS : 737-1965	SIB	Sheet, Strip	O	6·5	—	30								
IS : 733-1967	EIB	Bars, Rods	M	6·5	—	25								
IS : 1285-1958	VIB	Extruded	M	6·3	—	25								
IS : 736-1966	PIB	Plate	½H	10	—	8	2·11	2·08	2·00	1·90	1·65	1·41	1·12	
IS : 737-1965	SIB	Sheet, Strip	½H	10	—	8								
IS : 737-1965	NS3	Sheet, Strip	O	10	—	30	2·30	2·22	2·00	1·89	1·69	1·48	1·26	
IS : 373-1965	NS3	Sheet, Strip	½H	14	—	7	3·46	3·37	3·25	3·09	2·82	2·46	2·18	
IS : 736-1965	NP4	Plate	M	19	—	12	4·35	4·35	4·32	4·20	3·80	3·27	2·46	
IS : 737-1965	NS4	Sheet, Strip	O	17·5	—	18								
IS : 733-1967	NE4	Bars, Rods	M	17·5	—	18								
IS : 738-1966	NT4	Drawn Tube	O	17·5	—	18								
IS : 1285-1958	NV4	Extruded Tubes	M	17·3	—	18								
IS : 737-1965	NS4	Sheet, Strip	¼H	20·5	—	8	5·45	5·42	5·27	4·98	4·50	3·94	2·46	
IS : 738-1966	NT4	Drawn Tube	½H	23·5	—	5	5·97	5·95	5·78	5·40	4·85	4·28	2·46	
IS : 737-1965	NS4	Sheet, Strip	½H	23·5	—	5								

(*Continued*)

TABLE A.3 ALLOWABLE STRESS VALUES FOR ALUMINIUM AND ALUMINIUM ALLOYS IN TENSION — *Contd*

Material	Grade and Products		Condition	Mechanical Properties			Allowable Stress Values in kgf/mm² at Design Temperature °C							Remarks
				Tensile Strength *Min* kgf/mm²	0·2 Proof Stress *Min* kgf/mm²	Elongation on $4\sqrt{S_0}$ *Min* Percent	Up to 50	Up to 75	Up to 100	Up to 125	Up to 150	Up to 175	Up to 200	
IS : 737-1965	NS5	Sheet, Strip	O	22	—	18*	5·49	—	—	—	—	—	—	—
IS : 733-1967	NE5	Bars, Rods and Sections	M	22	—	18*								
IS : 738-1966	NT5	Drawn Tubes	O	22	—	18*								
IS : 1285-1958	NV5	Hollow Section	M	22	—	18*								
IS : 737-1965	NS6	Sheet, Strip	O	27	—	18*	6·68	—	—	—	—	—	—	
IS : 738-1966	NT6	Drawn Tubes	O	27	—	18*								
IS : 736-1966	NP6	Plate	O	27	—	20*								
IS : 733-1967	NE6	Bars, Rods	M	27	—	18*								
IS : 1285-1958	NV6	Extruded Tubes	M	26·8	—	18*								
IS : 733-1967	NE8	Bars, Rods, and Sections	O	27	—	16	7·02	—	—	—	—	—	—	
IS : 1285-1958	HV9	Extruded Round Tubes Hollow Section	M	11	—	15	2·97	2·90	2·78	2·67	2·53	1·93	1·33	
IS : 1285-1958	HV9	do	P	15·7	—	10	3·74	3·61	3·38	3·24	2·95	2·18	1·41	
IS : 1285-1958	HV9	do	WI	18·9	—	12	5·15	4·91	4·65	4·29	3·16	2·18	1·41	

IS : 736-1966	HP30	Plate	W	20·5	11·0	15								
IS : 734-1967	HF30	Forging	W	19·0	11·0	18								
IS : 737-1965	HS30	Sheet, Strip	W	20·5	11·0	15	5·18	5·01	4·86	4·71	4·50	3·94	2·81	
IS : 733-1967	HE30	Bars, Rods and Sections	W	19·0	11·0	18								
IS : 738-1966	HT30	Drawn Tube	W	22·0	11·0	16								
IS : 738-1966	HT30	Drawn Tube	WP	31·5	25·0	7								
IS : 736-1966	HP30	Plate	WP	30	23·5	8								
IS : 734-1967	HF30	Forging	WP	30	25	10	7·29	7·10	6·85	6·60	5·56	4·36	3·10	
IS : 737-1965	HS30	Sheet, Strip	WP	30	25·5	8								—
IS : 733-1967	HE30	Bars, Rods and Sections	WP	30	25·0	10								
IS : 1285-1958	HB15	Bolting alloy	WP	44	38·0	8	8·82	8·45	7·95	7·30	5·06	3·09	2·11	
S : 1285-1958	NB6	Bolting alloy	½H	31·5	23·5	—	7·65	—	—	—	—	—	—	
IS : 1284-1966	HB30	Bolting alloy	WP	30·0	25·0	—	5·85	5·70	5·48	5·27	4·43	3·44	2·32	
IS : 617-1959	A-3	Casting alloy	M (sand cast)	16·5	—	8·0*	2·59	2·36	2·25	2·14	1·90	1·72	1·55	
			M (chill cast)	18·9	—	12·0*	2·96	2·68	2·56	2·46	2·18	1·97	1·76	

*The elongation values are based on 50·8 mm test piece.

A-1.4 Allowable stress values for copper and copper alloys are given in Table A.4.

TABLE A.4 ALLOWABLE STRESS VALUES FOR COPPER AND COPPER ALLOYS

Material Specification	Grade Product	Mechanical Properties			Allowable Stress Values in kgf/mm² at Design Temperature °C												
		Tensile Strength *Min* kgf/mm²	Yield Stress *Min* kgf/mm²	Elongation Percent *Min*	Up to 50	Up to 75	Up to 100	Up to 125	Up to 150	Up to 175	Up to 200	Up to 225	Up to 250	Up to 275	Up to 300	Up to 325	Up to 350
				Plate, Sheet and Strip													
IS : 410-1967	Cu Zn 30	28	—	45	7·03	7·03	7·03	7·03	6·96	5·70	3·83	2·46	—	—	—	—	—
	Cu Zn 37	28	—	45	8·79	8·67	8·30	7·81	7·28	5·38	2·00	—	—	—	—	—	—
	Cu Zn 40	28	—	30	8·79	8·67	8·30	7·81	7·28	5·38	2·00	—	—	—	—	—	—
IS : 1972-1961	All grades	22·5	—	35	4·71	4·66	4·54	4·30	3·47	2·71	1·90	—	—	—	—	—	—
				Bars and Rods													
IS : 288-1960	—	40	—	22	7·03	7·03	7·03	7·03	6·96	5·70	3·83	2·46	—	—	—	—	—
IS : 4171-1967	—	40	—	22	7·03	7·03	7·03	7·03	6·96	5·70	3·83	2·46	—	—	—	—	—
				Bolting Material													
IS : 288-1960	—	40	—	22	1·76	1·76	1·76	1·67	1·54	1·48	1·41	—	—	—	—	—	—
IS : 4171-1967	—	40	—	22	1·76	1·76	1·76	1·67	1·54	1·48	1·41	—	—	—	—	—	—
				Sections													
IS : 291-1966	Grade 1	35	—	20	8·79	8·67	8·30	7·81	7·28	5·38	2·00	—	—	—	—	—	—
	Grade 2	35	—	20	8·79	8·67	8·30	7·81	7·28	5·38	2·00	—	—	—	—	—	—
				Tubes													
IS : 407-1966	Alloy 1	29	—	—	7·03	7·03	7·03	7·03	6·96	5·70	3·83	—	—	—	—	—	—
	Alloy 2	29	—	—	8·79	8·67	8·30	7·81	7·28	5·38	2·00	—	—	—	—	—	—
IS : 1545-1960	ISBT 1 ISBT 2	—	—	—	7·03	7·03	7·03	7·03	6·96	5·70	3·83	—	—	—	—	—	—
	ISABT	—	—	—	8·44	8·44	8·44	8·44	8·28	5·43	2·58	1·58	—	—	—	—	—
	ISABZT	—	—	—	8·76	8·67	8·53	8·34	8·09	7·09	4·64	3·16	1·88	—	—	—	—
IS : 2371-1963	Cu Zn 21 Al 2 As	32	—	—	8·44	8·44	8·44	8·44	8·28	5·43	2·58	1·58	—	—	—	—	—
	Cu Ni 31 Mn 1 Fe	42	—	—	8·31	8·08	7·89	7·71	7·59	7·58	7·27	7·14	7·11	6·92	6·83	6·73	6·66
IS : 2501-1963		—	—	—	4·22	4·19	4·13	4·00	3·47	2·71	1·90	—	—	—	—	—	—
				Castings													
IS : 318-1962	Grade 1	22	11·5	12	5·94	5·88	5·82	5·76	5·69	5·56	5·38	5·13	4·78	4·00	—	—	—
	Grade 2	19	11	7·5	5·21	5·09	4·96	4·84	4·77	4·65	4·58	—	—	—	—	—	—
	Grade 3	17·5	7·5	7·0	4·30	4·12	3·90	3·78	3·65	3·52	3·50	—	—	—	—	—	—

A-2. LIST OF INDIAN STANDARDS ON MATERIALS SPECIFIED IN TABLES A.1 TO A.4

Sl No.	*No. of the Standard*	*Title*
1)	IS : 288-1960	Specification for copper rods for boiler stay bolts and rivets (*revised*)
2)	IS : 291-1961	Specification for naval brass rods and sections (suitable for machining and forging) (*revised*)
3)	IS : 318-1962	Specification for leaded tin bronze ingots and castings (*revised*)
4)	IS : 320-1962	Specification for high tensile brass rods and sections (*revised*)
5)	IS : 407-1966	Specification for brass tubes for general purposes (*second revision*)
6)	IS : 410-1959	Specification for rolled brass steel plate, sheet, strip and foil (*revised*)
7)	IS : 617-1959	Specification for aluminium and aluminium alloy ingots and castings for general engineering purposes (*revised*)
8)	IS : 733-1967	Specification for wrought aluminium and aluminium alloys, bars, rods and sections (for general engineering purposes) (*first revision*)
9)	IS : 734-1967	Specification for wrought aluminium and aluminium alloys, forgings (for general engineering purposes) (*first revision*)
10)	IS : 736-1965	Specification for wrought aluminium and aluminium alloys, plate (for general engineering purposes) (*revised*)
11)	IS : 737-1965	Specification for wrought aluminium and aluminium alloys, sheet and strip (for general engineering purposes) (*revised*)
12)	IS : 738-1966	Specification for wrought aluminium and aluminium alloys, drawn tube (for general engineering purposes) (*revised*)
13)	IS : 961-1962	Specification for structural steel (high tensile) (*revised*)
14)	IS : 1284-1966	Specification for wrought aluminium alloys, bolt and screw stock for general engineering purposes (*revised*)
15)	IS : 1285-1968	Specification for wrought aluminium and aluminium alloys, extruded round tube and hollow sections (for general engineering purposes) (*revised*)
16)	IS : 1385-1959	Specification for phosphor bronze rods and bars, sheet and strip, and wire
17)	IS : 1545-1960	Specification for solid drawn copper alloy tubes
18)	IS : 1570-1961	Schedules for wrought steels for general engineering purposes
19)	IS : 1914-1961	Specification for carbon steel boiler tubes and superheater tubes
20)	IS : 1972-1961	Specification for copper plate, sheet and strip for industrial purposes
21)	IS : 1978-1961	Specification for line pipe
22)	IS : 1979-1961	Specification for high test line pipe
23)	IS : 1990-1961	Specification for steel rivet and stay bars for boilers
24)	IS : 2002-1962	Specification for steel plates for boilers
25)	IS : 2004-1962	Specification for carbon steel forgings for general engineering purposes
26)	IS : 2040-1962	Specification for steel bars for stays
27)	IS : 2041-1962	Specification for steel plates for pressure vessels
28)	IS : 2062-1969	Specification for structural steel (fusion welding quality) (*first revision*)
29)	IS : 2371-1963	Specification for solid drawn copper alloy tubes for condensers, evaporators, heaters and coolers using saline and hard water
30)	IS : 2416-1963	Specification for boiler and superheater tubes for marine and naval purposes
31)	IS : 2501-1963	Specification for copper tubes for general engineering purposes
32)	IS : 2611-1964	Specification for carbon chromium molybdenum steel forgings for high temperature service
33)	IS : 2856-1964	Specification for carbon steel castings suitable for high temperature service (fusion welding quality)
34)	IS : 3038-1965	Specification for alloy steel castings for pressure containing parts suitable for high temperature
35)	IS : 3039-1965	Specification for structural steel (shipbuilding quality)
36)	IS : 3444-1966	Specification for corrosion resistant steel castings
37)	IS : 3503-1966	Specification for steel for marine boilers, pressure vessels and welded machinery structures
38)	IS : 3609-1966	Specification for chrome molybdenum steel, seamless, boiler and superheater tubes
39)	IS : 3945-1966	Specification for steel for naval purposes
40)	IS : 4171-1967	Specification for copper rods for general engineering purposes

APPENDIX B

(*Clause* 2.2.1.1)

ELEVATED TEMPERATURE VALUES FOR CARBON AND LOW ALLOY STEELS WITH UNCERTIFIED HIGH TEMPERATURE PROPERTIES

B-0. General — This appendix specifies the values of elevated temperature proof stress and average stress for rupture in 100 000 hours, to be used in case of carbon and low alloy steels with uncertified elevated temperature properties. The allowable stress values specified in Table A.1 have been calculated on the basis of these values and the criteria given in Table 2.1.

B-1. Types of Steels Covered — The values for six steels of different chemical composition have been covered in Table **B**.2 and Table **B**.3.

The composition of these steels is given in Table B.1.

TABLE B.1 CHEMICAL COMPOSITION OF STEELS

Type	C *Max*	Mn	Cr	Mo	P	S
A	0·25	1·40 *Max*	—	—	0·05	0·05
B	0·20	1·50 *Max*	—	0·60	0·04	0·04
C	0·20	0·40 to 0·70	0·40 to 0·70	0·40 to 0·70	0·04	0·04
D	0·18	0·40 to 0·70	0·70 to 1·50	0·40 to 0·70	0·04	0·04
E	0·15	0·40 to 0·70	2·00 to 3·25	0·90 to 1·15	0·04	0·04
F	0·15	0·40 to 0·70	4·00 to 6·00	0·40 to 0·70	0·04	0·04

TABLE B.2 MINIMUM VALUES FOR THE RATIO OF 0·2 PERCENT PROOF STRESS AT ELEVATED TEMPERATURES TO THE MINIMUM SPECIFIED YIELD STRENGTH AT ROOM TEMPERATURE, E_t/E_{20} IN kgf/mm²

Temp, °C	Type of Steel						
	A		B	C	D	E	F
	C and C-Mn		C-Mo	½Cr-½Mo	1Cr-½Mo	2¼Cr-1Mo	5Cr-½Mo
	(Note 1)	(Except Note 1)					
50	1·0	1·0	1·0	1·0	1·0	1·0	1·0
100	0·89	0·92	0·93	0·93	0·93	0·94	0·93
150	0·80	0·85	0·88	0·88	0·89	0·90	0·89
200	0·71	0·77	0·82	0·82	0·85	0·87	0·85

(*Continued*)

TABLE B.2 MINIMUM VALUES FOR THE RATIO OF 0·2 PERCENT PROOF STRESS AT ELEVATED TEMPERATURES TO THE MINIMUM SPECIFIED YIELD STRENGTH AT ROOM TEMPERATURE, E_t/E_{20} IN kgf/mm² — *Contd*

Temp, °C	Type of Steel						
	A		B	C	D	E	F
	C and C-Mn		C-Mo	½Cr-½Mo	1Cr-½Mo	2¼Cr-1Mo	5Cr-½Mo
	(Note 1)	(Except Note 1)					
250	0·63	0·70	0·77	0·77	0·80	0·84	0·80
300	0·56	0·64	0·71	0·71	0·76	0·81	0·76
350	0·49	0·58	0·66	0·66	0·72	0·77	0·72
400	0·43	0·53	0·62	0·62	0·67	0·74	0·67
450	—	—	0·58	0·58	0·63	0·70	0·63
500	—	—	—	—	0·59	0·66	0·59

NOTE 1 — This column applies to fine-grain aluminium killed, and similar steels, ordinarily used for low temperatures (below 0°C).

TABLE B.3 AVERAGE STRESSES FOR RUPTURE, S_R IN 100 000 HOURS IN kgf/mm²

Temp, °C	Type of Steel					
	A	B	C	D	E	F
	C and C-Mn	C-Mo	½Cr-½Mo	1Cr-½Mo	2¼Cr-1Mo	5Cr-½Mo
250	—	—	—	—	—	—
400	12·5	—	—	—	—	—
450	6·5	16·9	16·9	—	—	—
475	5·4	11·6	11·6	17·6	19·0	13·4
500	3·3	8·4	8·4	13·0	14·4	9·9
525	—	5·6	5·6	8·8	10·6	7·0
550	—	3·5	3·5	5·3	7·4	5·3
575	—	2·1	2·1	3·2	4·9	3·5
600	—	—	—	2·1	3·5	2·8

APPENDIX C

(*Clauses* 2.2.2, 3.13 *and* 3.13.2.3)

STRESSES FROM LOCAL LOADS ON, AND THERMAL GRADIENTS IN, PRESSURE VESSELS

Design Criteria and Recommended Methods of Calculation

C-1. INTRODUCTION

C-1.1 Systems of local stresses (in addition to those at the junction of branches and shell due to pressure) are produced in the shells of pressure vessels from:

a) local loads arising from;
   1) supports for the vessel,
   2) structures (both internal and external) supported by the vessel, and
   3) loads imposed on branches by piping systems, etc;
b) steady and transient thermal gradients; and
c) local areas and lines of stiffening or thickening of the shell.

C-1.2 In the assessment of loads consideration shall always be given to the possibility of loads arising from differential thermal expansion of the shell and the parts attached to it. All the types of local load mentioned above give rise to bending stresses in the shell which decrease rapidly with distance from the area of application of the load; they may also modify the membrane stresses.

C-1.3 Thermal gradients through the thickness of the shell give rise to bending stresses; longitudinal thermal gradients to a combination of membrane and bending stresses. The permissible values of the membrane stresses are dealt within **3.3.2.4** at equation (3.8) and conditions in equations (3.9a) to (3.9f). This appendix deals firstly with the permissible values of the bending stresses and secondly with methods of estimating bending stress from loading conditions in some particular cases.

C-2. DESIGN CRITERIA

C-2.1 General — The design criterion to be adopted depends on whether or not the local bending stress system extends over a small or a large proportion of the circumference of the vessel. In the former case the criterion adopted is that the bending stresses are limited to the value which will just cause a plastic hinge to develop; the criterion is considered safe because a very small amount of distortion consequent upon the formation of a plastic hinge will cause a local increase in membrane stresses which will inhibit further distortion. The stress intensification factor corresponding to this condition is of the same order as that occurring at branches under the action of pressure.

If, however, the highly stressed area extends over a considerable fraction of the circumference of the vessel, loads approaching the plastic limit are liable to cause a kink to form in the shell. Under these conditions the allowable value of the bending stresses has been reduced (*see* **C-2.3**, **C-2.4** and **C-2.5**).

The general equation relating the lower limit of the bending stress components which will just produce fully plastic conditions, to the membrane stress components, is:

$$\frac{\sigma_{e,b}}{\sigma_y} = \frac{3}{2}\left[1 - \left(\frac{\sigma_{e,d}}{\sigma_y}\right)^2\right] \qquad \ldots \text{(C.1)}$$

This equation has been deduced for a beam of rectangular cross section subjected to direct and bending loads; using the Tresca yield criterion to determine equivalent stresses it may be shown to give the lower limit of stresses to produce full plasticity in the case of biaxial stress systems.

It is, however, convenient to use equation (3.8) of **3.3.2.4** for the calculation of the equivalent direct stress $\sigma_{e,d}$, that is:

$$\sigma_{e,d} = [\, \sigma_\theta^2 - \sigma_\theta \sigma_z + \sigma_z^2 + 3\,\tau^2]^{\frac{1}{2}}$$

and it is recommended that the value of $\sigma_{e,b}$ calculated from equation (C.1) using this value for $\sigma_{e,d}$ should be reduced by 15 percent to allow for the possible difference between the yield stresses given by the Tresca and Maxwell criteria. Therefore, for design purposes and provided the highly stressed areas are effectively far from welded seams with a joint factor J less than 1, equation (C.1) above should be replaced by:

$$\frac{\sigma_{e,b}}{f} = 1{\cdot}91 - 0{\cdot}85\left(\frac{\sigma_{e,d}}{f}\right)^2 \qquad \ldots \text{(C.2)}$$

It is recommended that this equation should continue to be applied even at temperatures where the behaviour of the material no longer approximates to that of an elastic perfectly plastic solid.

If a welded seam with a joint factor J less than 1 crosses or is adjacent to the highly stressed area, fJ should replace f in equation (C.2).

It should be noted that under test conditions

$$\sigma_{e,d}/\sigma_y \leqslant 0{\cdot}87 \left[\frac{\sigma_{e,d}}{f} \leqslant 1{\cdot}3\right]$$

whereas under design conditions

$$\sigma_{e,d}/\sigma_y \leqslant 0{\cdot}67 \left[\frac{\sigma_{e,d}}{f} \leqslant 1\right]$$

The permissible value of the bending stresses is, therefore, affected by whether or not the stresses are applied when the vessel is under test and,

therefore, subjected to enhanced membrane stresses. Examples of the two categories are :

a) local bending stresses present at test conditions, such as horizontal pressure storage tank supported on saddles (the stresses at the horns of the saddle); and
b) local bending stresses present only at design conditions, such as pad for attachment of an auxiliary structure not loaded during test and thermal stresses.

Finally, if there are no welded seams in the vicinity of the loaded areas, the permissible values of the bending stresses are higher for vessels for which a welded joint factor of 0·85 and, therefore, lower membrane stresses have been adopted than for vessels for which a welded joint factor of 1·0 has been adopted.

Table C.1 gives the permissible values of the bending stresses, calculated and adjusted as above, for the normal case in which the loaded area is small and the direct stresses have their full design value. Definitions of three size classifications of loaded areas, and of the bending stress levels permissible for each, are given in **C-2.2** to **C-2.4**. The methods of calculation for shell stresses due to local loads given in **C-3** are generally applicable only to 'small' loaded areas. The formal definition of equivalent bending stress in the biaxial case is given in **C-2.5**. Table C.2 gives the notations used in **C-2**.

C-2.2 Loaded Areas — Small

C-2.2.1 *Size of Loaded Area* — A loaded area is considered 'small' if it extends over less than one-third of the circumference of the vessel, and the rules of this clause are then applicable.

C-2.2.2 *Permissible Value of Bending Stress* — When the loaded area is 'small' as defined in **C-2.2.1**, the maximum permissible values of the local bending stresses are as given by equation (C.2). Table C.1 tabulates the values applicable to cases where the membrane stresses have their design values.

C-2.3 Loaded Areas—Large

C-2.3.1 *Size of Areas* — A loaded area is considered 'large' when it extends over at least half the circumference of the vessel.

C-2.3.2 *Permissible Value of Bending Stresses* — When the loaded area is 'large' as defined by **C-2.3.1**, the permissible value of the bending stresses shall be two-thirds of the values given by equation (C.2).

C-2.4 Loaded Areas of Intermediate Size

C-2.4.1 *Size of Areas* — A loaded area is considered of 'intermediate' size if it extends over between one-third and one-half of the vessel circumference.

C-2.4.2 *Permissible Value of Bending Stresses* — When the loaded area is of intermediate size, the permissible value of the bending stress shall be interpolated linearly in respect of the size of the loaded area between the values appropriate to 'small' and 'large' loaded areas.

C-2.5 Biaxial Bending Stresses — Cases may arise in which biaxial bending stresses are present. In these cases the principal values of the bending stresses shall be determined and the Tresca criterion applied to determine the equivalent bending stress, thus:

a) if the principal bending stresses are of the same sign:

$$\sigma_{e,b} = |\sigma_{1,b}| \quad \ldots \quad (C.3a)$$

b) if the principal bending stresses are of opposite sign

$$\sigma_{e,b} = |\sigma_{1,b}| + |\sigma_{2,b}| \quad \ldots \quad (C.3b)$$

The equivalent bending stress shall not exceed the appropriate value given in **C-2.2**, **C-2.3**, and **C-2.4** depending on the size of the loaded area.

The bending stresses shall be computed by elastic theory, and are allowed as an addition to the direct or membrane stresses permitted by **3.3**.

Table C.1 gives allowable local bending stresses in shell for the conditions that:

a) membrane stresses have design values (*see* Notes 1, 2 and 3);
b) loaded areas extend over not more than one-third of circumference of vessel (*see* Note 4).

TABLE C.1 ALLOWABLE LOCAL BENDING STRESSES IN SHELL

(*Clauses* C-2.2.2 *and* C-2.5)

Weld joint factor J	1	0·85	0·85
Distance between nearest welded seam and loaded area	any	$< (\overline{Ri})^{\frac{1}{2}}$	$> (\overline{Ri})^{\frac{1}{2}}$
—	allowable local equivalent bending stresses (*see* Note 5)		
Test conditions controlling (local load present during test)	$0{\cdot}5 f_a$		$0{\cdot}85 f_a$
Design conditions controlling (local load absent during test, or $f < 0{\cdot}5 f_a$)	f		$1{\cdot}3 f$

NOTE 1 — The criteria which govern the allowable design stress are stated in **2.2**.

NOTE 2 — Rules for the calculation of the minimum shell thickness for cases of both simple pressure and combined loadings are given in **3.3.2**.

NOTE 3 — If the shell is made thicker than required by **3.3.2** so that the membrane stresses are reduced below the design values, the allowable local bending stresses may be calculated from equation (C.2). They may, however, never exceed $1{\cdot}91 f$.

NOTE 4 — If the loaded area extends over more than ½ the circumference of the vessel the allowable bending stresses are reduced (*see* C-2.4 and C-2.5).

NOTE 5 — The equivalent bending stress is to be calculated from equation (C.3a) or (C.3b) as appropriate.

TABLE C.2 NOTATION FOR CLAUSE C-2

Symbol	Significance	Units
f	Design stress	kgf/mm²
f_a	Design stress at ambient temperature	kgf/mm²
t	Thickness of shell plate	mm
R	Mean radius of shell	mm
$\sigma_{e,b}$	Equivalent value of the bending stresses	kgf/mm²
$\sigma_{e,d}$	Equivalent value of the direct (membrane) stresses	kgf/mm²
$\sigma_{1,b}$	Numerically greater principal bending stress	kgf/mm²
$\sigma_{2,b}$	Numerically smaller principal bending stress	kgf/mm²
$\|\ \|$	Modulus (numerical value without regard to sign) of	—
σ_y	Yield (0·2 percent proof) stress in direct tension at appropriate temperature	kgf/mm²
$\sigma_s, \sigma_\theta, T$	*See* 3.3.2.4	kgf/mm²

C-3. LOCAL LOADS ON PRESSURE VESSEL SHELLS

C-3.1 Introduction

C-3.1.1 This section is concerned with the effects on the shell of a pressure vessel of local forces and moments which may come from supports, equipment supported from the vessel, for example, agitator drives, or thrusts from pipework connected to branches.

The application of the data to the design of supports is treated in **C-4** and to the design of branches in **C-3.5** with particular reference to the thrusts due to the thermal forces in pipework which may be connected to the branch.

The data are presented in the form of charts in terms of non-dimensional functions of the variables so that any convenient system of consistent units may be used. The units given in the list of symbols are those recommended for general use.

C-3.1.2 *Notation*

Symbol	*Unit*	*Description*
C	mm	Half length of side of square loading area.
C_1	mm	Half side of equivalent square loading area.
C_x	mm	Half length of rectangular loading area in longitudinal direction.
C_x	mm	Axial length of loading area for an external longitudinal moment (*see* Fig. C.21).
C_θ	mm	Circumferential length of loading area for an external circumferential moment (*see* Fig. C.20).
C_ϕ	mm	Half length of rectangular loading area in circumferential direction.
d	mm	Distance from centre of applied load to mid-length of vessel.
E	kgf/mm²	Modulus of elasticity.
f_x	kgf/mm²	Resultant longitudinal stress.
f_ϕ	kgf/mm²	Resultant circumferential stress.
i	radians	Rotation of a fitting by an external moment.
L	mm	Length of cylindrical part of shell.
L_e	mm	Equivalent length of shell.
M	kgf mm	External moment applied to a branch or fitting.
M_x	kgf mm/mm	Longitudinal or meridional bending moment per unit circumference.
M_ϕ	kgf mm/mm	Circumferential bending moment per unit length.
N_x	kgf/mm	Longitudinal membrane force per unit circumference.
N_ϕ	kgf/mm	Circumferential membrane force per unit length.
r	mm	Radius of cylinder or sphere.
r_o	mm	Radius of branch.
t	mm	Wall thickness of shell.
W	kg	External load distributed over the loading area.
x	mm	Longitudinal distance of a point in the vessel wall, from the centre of the loading area.
δ	mm	Deflection of a cylinder at load or at any point of a sphere.
δ_1	mm	Deflection of a sphere at the edge of the loaded area.
θ	radians	Polar co-ordinate of a point on a spherical vessel.
ϕ	radians	Cylindrical co-ordinate of a point in the vessel wall.

The units given above in this clause are the consistent units recommended for general use and used in the worked examples. Any other system of consistent units can be used when it is convenient. Additional numerical subscripts are used to distinguish values of M_x, M_ϕ, N_x, and N_ϕ at different positions when required.

C-3.2 Radial Loads on Cylindrical Shells

C-3.2.1 *Stresses at the Edge of the Loaded Area* — The maximum stresses are at the edge of the loaded area. Figure C.1 shows a cylindrical vessel subjected to a radial load distributed over a central rectangular area $2C_x \times 2C_\phi$.

The cylindrical shell wall of the vessel is assumed to be simply supported at the ends, which means that the radial deflections, the bending moments, and the membrane forces in the shell wall are assumed to be zero there. Since the stresses and deflection due to the load are local and die out rapidly away from the loaded area, this is equivalent to assuming that the loaded area is remote from the ends.

C-3.2.1.1 *Off centre loading* — If the loaded area is distant d from the centre of the length of a vessel of length L, the deflections, bending moments and membrane forces may be assumed to be equal to those in a vessel of length L_e loaded at its mid-length. L_e is called the equivalent length and can be found from:

$$L_e = L - \frac{4d^2}{L}$$

Figure C.2 shows a cylindrical shell loaded in this way and Fig. C.3 gives a graph of $\frac{L_e}{L}$ against $\frac{d}{L}$ which can be used to find L_e.

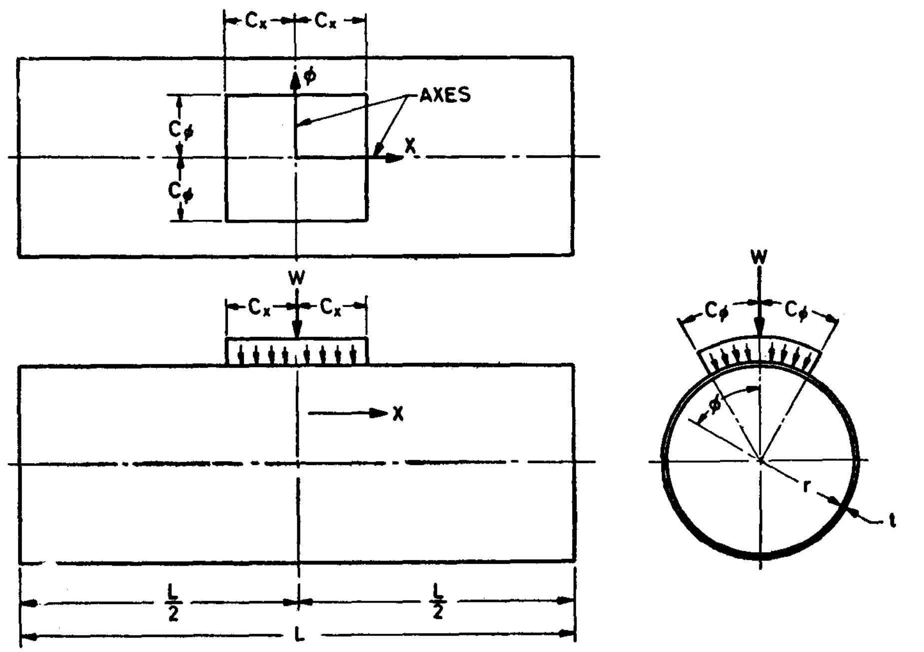


Fig. C.1 Radial Loads on Cylindrical Shells

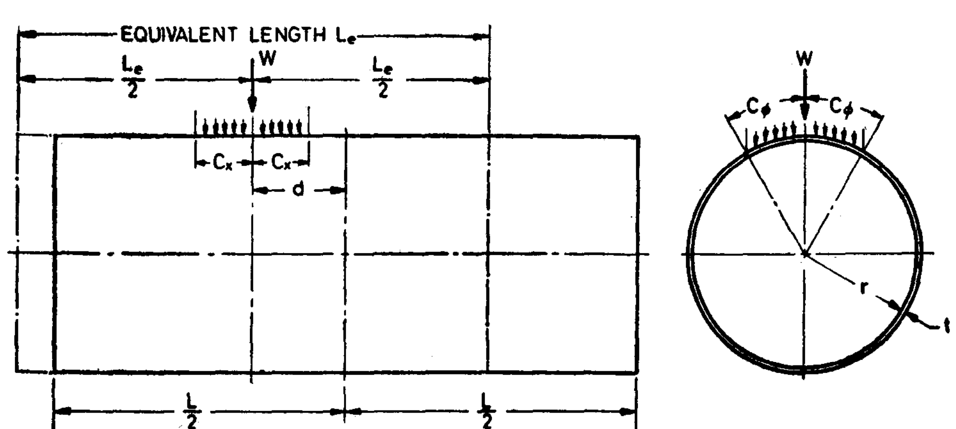


Fig. C.2 Vessel with Radial Load Out of Centre

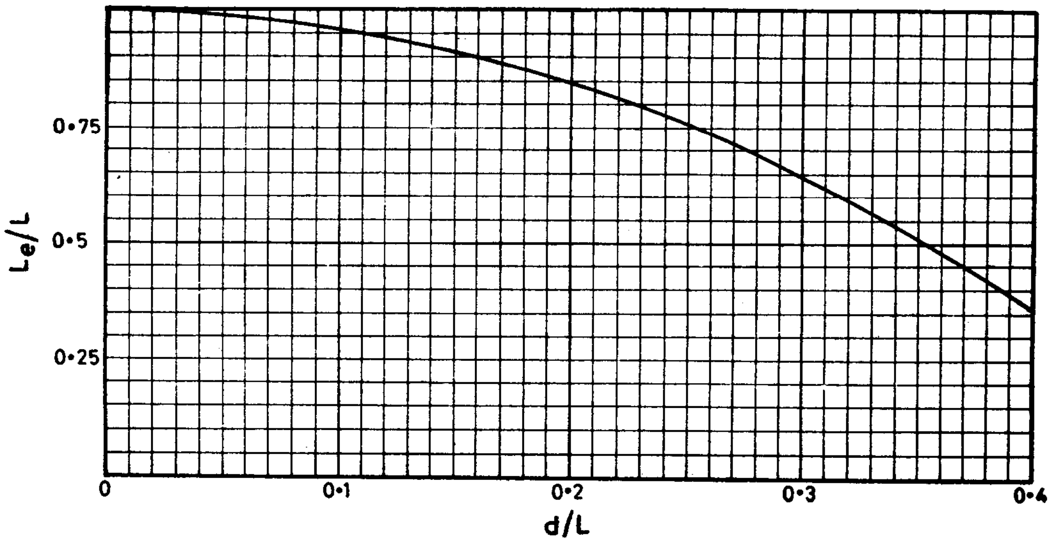


FIG. C.3 GRAPH FOR FINDING EQUIVALENT LENGTH L_e

C-3.2.1.2 *Determination of stresses* — The resultant longitudinal stress in the shell is given by:

$$f_x = \frac{N_x}{t} \pm \frac{6M_x}{t^2}$$

the resultant hoop stress is given by:

$$f_\phi = \frac{N_\phi}{t} \pm \frac{6M_\phi}{t^2}$$

N_x and N_ϕ are positive for tensile membrane stresses.

M_x and M_ϕ are positive when they cause compression at the outer surface of the shell.

These quantities depend on the ratios

$$\frac{\text{Axial length of load}}{\text{Actual or equivalent length}} = \frac{2C_x}{L}$$

and $\dfrac{\text{Circumferential length of loaded area}}{\text{Axial length of loaded area}} = \dfrac{2C\phi}{2C_x}$

For a circular area of radius r_0, $C_\phi = C_x = 0{\cdot}85\, r_0$ gives a safe approximation. Non-dimensional functions of each can be expressed in terms of the non-dimensional group; $64\,\frac{r}{t}\left(\frac{C_x}{r}\right)^2$.

The numerical factor 64 is a scale factor without theoretical significance and the value of the expression can be found by calculation or from Fig. C.4 when r, t and C_x are known. The moments and membrane forces are found by interpolation from the graphs of Fig. C.5, C.6, C.7 and C.8.

Each of the four graphs in each set is for a given value of the ratio $2C_x/L$ and has curves for four values of the ratio C_ϕ/C_x.

The circumferential moment M_ϕ is found from Fig. C.5.

The longitudinal moment M_x is found from Fig. C.6.

The circumferential membrane force N_ϕ is found from Fig. C.7.

The longitudinal membrane force N_x is found from Fig. C.8.

A moment is considered as positive if it causes compression at the outside of the vessel.

A membrane force is considered as positive if it causes tension in the vessel wall.

C-3.2.1.3 *Effect of internal pressure* — A conservative result is obtained for the total stresses if the hoop and longitudinal stresses due to the pressure are simply added to those due to local radial loads calculated as above.

C-3.2.2 *Stresses Away from the Edge of the Loaded Area* — Although the maximum stresses occur at the edge of the load, it is necessary to find those at other positions when the effect of one load at the position of another is required.

This happens:

a) when longitudinal or circumferential moments are resolved as in **C-3.3**; and
b) when loads are applied close together, for example, if a bracket is fixed close to a branch.

In general the effect of one load at the position of another can be disregarded when the distance between the centres of the loaded areas is greater than $K_1.C_\phi$ for loads separated circumferentially or $K_2.C_x$ for loads separated axially, where K_1 and K_2 are found from the Table C.3 and C_ϕ and C_x are for the greater load.

The value of the non-dimensional factor $64\,\frac{r}{t}\left(\frac{C_x}{r}\right)^2$ can be found from Fig. C.4.

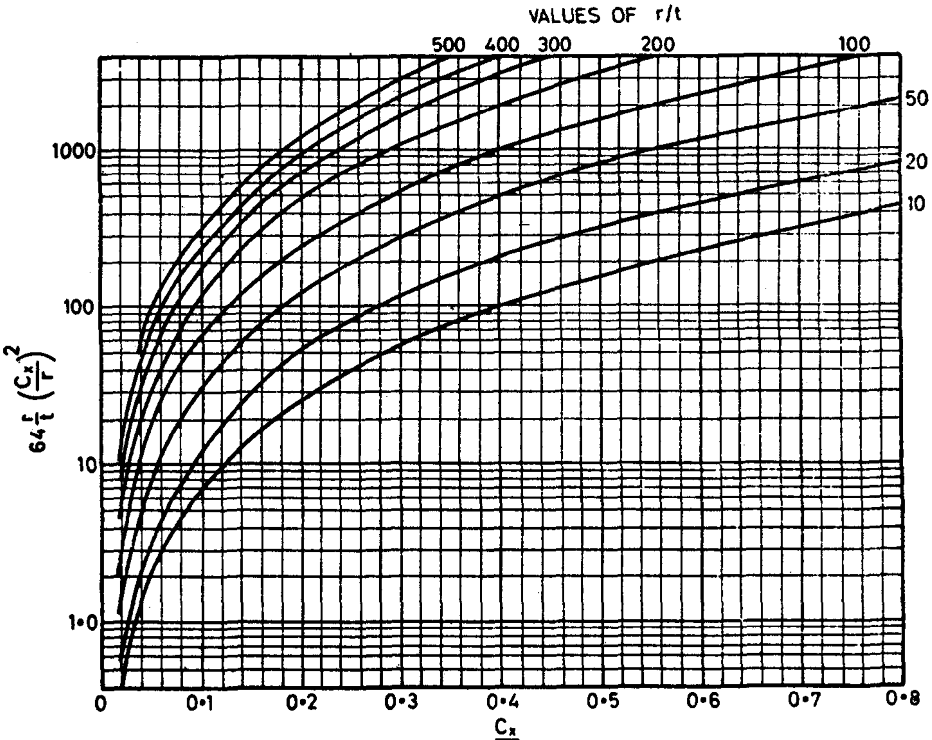


Fig. C.4 Chart for Finding $64\frac{r}{t}\left(\frac{C_x}{r}\right)^2$

TABLE C.3 VALUES OF FACTORS K_1 AND K_2

$64\frac{r}{t}\left(\frac{C_x}{r}\right)^2$	$\frac{2C_x}{L}$	K_1	K_2
0·4	0·01	8	8
	0·05	6	8
	0·2	3	4
	0·4	1·5	2
10	0·01	3	8
	0·05	2·5	8
	0·2	1·5	3
	0·4	1·5	2
200	0·01	Negligible	5
	0·05		4
	0·2		2·5
	0·4		1·75
3 200	All values	Negligible	2·5

C-3.2.2.1 *Variation of stress round the circumference* — No exact analytical treatment of the variation of stress round the circumference away from the edge of the loaded area is available. The following treatment is an approximation sufficiently accurate for practical purposes.

For an experimental verification of it, *see* Reference 17.

Consider a radial line load of length $2C_x$, applied at the mid-length of a thin cylinder as shown in Fig. C.9A. The maximum stresses due to this load at points away from it are on the circumference passing through its mid-length as A in the figure. The radius through A makes an angle ϕ_1 with the line of the load.

The moments and membrane forces at A, M_ϕ, M_x, N_ϕ, N_x can be found from the graphs of Fig. C.9, C.10, C.11 and C.12 in which the functions M_ϕ/W, M_x/W, $N_\phi.t/W$, and N_xt/W are plotted against the non-dimensional group $\phi_1.r/C_x$.

The diagram showing the load and its geometry, as Fig. C.9A, is repeated on each chart for convenience.

Line loads are, of course, unusual in practice, and loads distributed over an area having an appreciable circumferential width $2C_\phi$ are treated as follows:

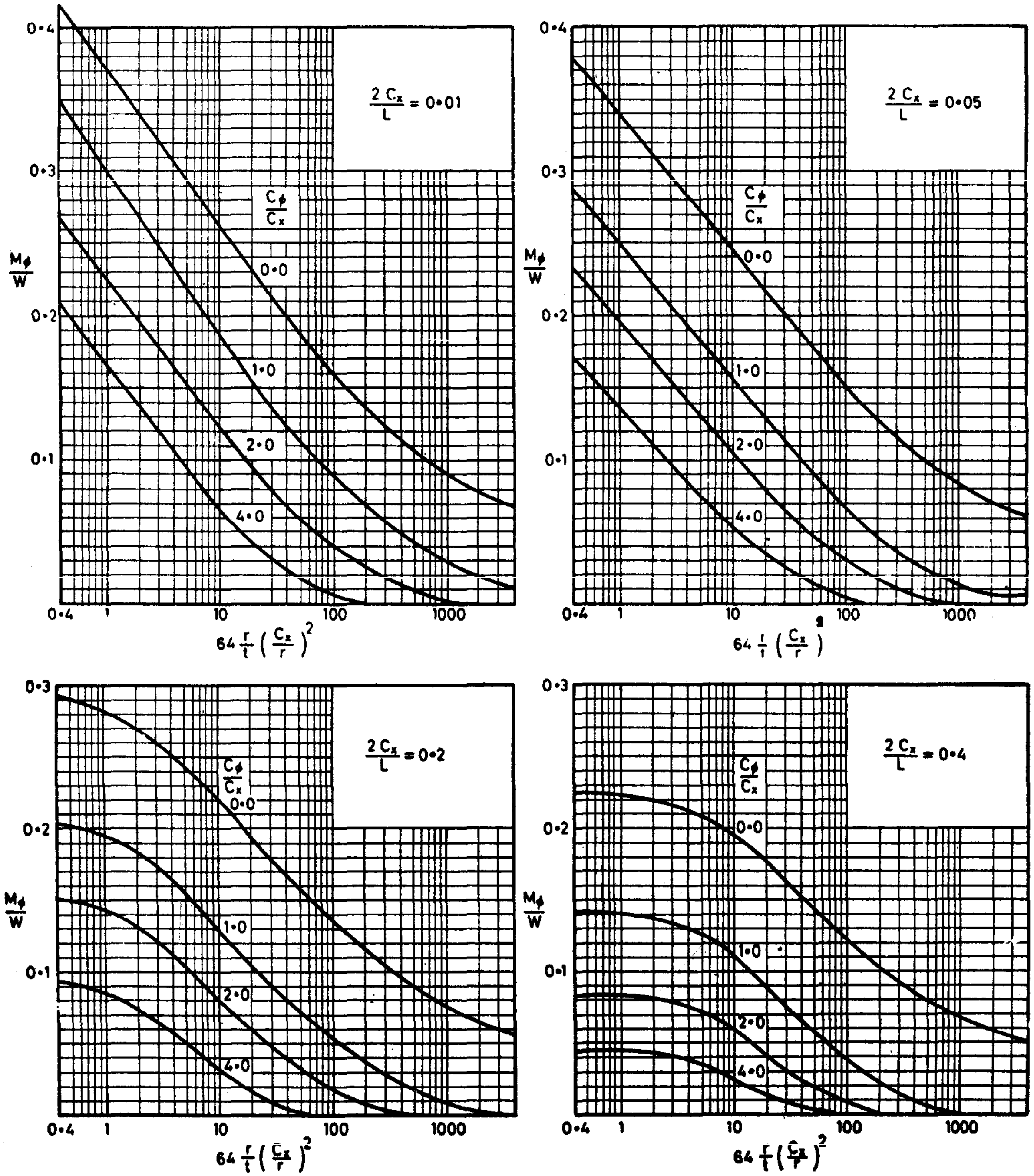
a) Find the value of the function $M\phi/W$, M_x/W, $N_\phi t/W$, or N_xt/W at the edge of the load for the known values of C_ϕ/C_x and $2C_x/L$ from the graphs in Fig. C.5, C.6, C.7 or C.8.

b) Enter the corresponding graph in Fig. C.9, C.10, C.11 or C.12 at this value.

The intercept on the curve for $2C_x/L$ gives a value of $\phi_1.r/C_x = Z$; for example, if $64\ r/t(C_x/r)^2 = 10$, $2C_x/L = 0{\cdot}01$ and $C_\phi/C_x = 1$, Fig. C.5 gives $M_\phi/W = 0{\cdot}185$. Entering Fig. C.9 at $M_\phi/W = 0{\cdot}185$ gives $Z = 0{\cdot}55$ for $2C_x/L = 0{\cdot}01$ as indicated by the dotted lines in the left-hand graph of Fig. C.9.

c) The value of M_ϕ/W at A is then found by substituting $(\phi_1 r/C_x - \mathcal{Z})$ for the actual value of $\phi_1 r/C_x$ in the same graph.

The other quantities M_x/W, $N_\phi t/W$, and $N_x t/W$ can be found in the same way. This method is used in order to avoid the use of a separate set of four charts for each value of C_ϕ/C_x considered.



For explanation *see* C-3.2. $64\frac{r}{t}\left(\frac{C_x}{r}\right)^2$ is found from Fig. C.4.

M_ϕ = Circumferential moment per mm width

W = Applied load

C_x = ½ × Axial loading length

C_ϕ = ½ × Circumferential loading length

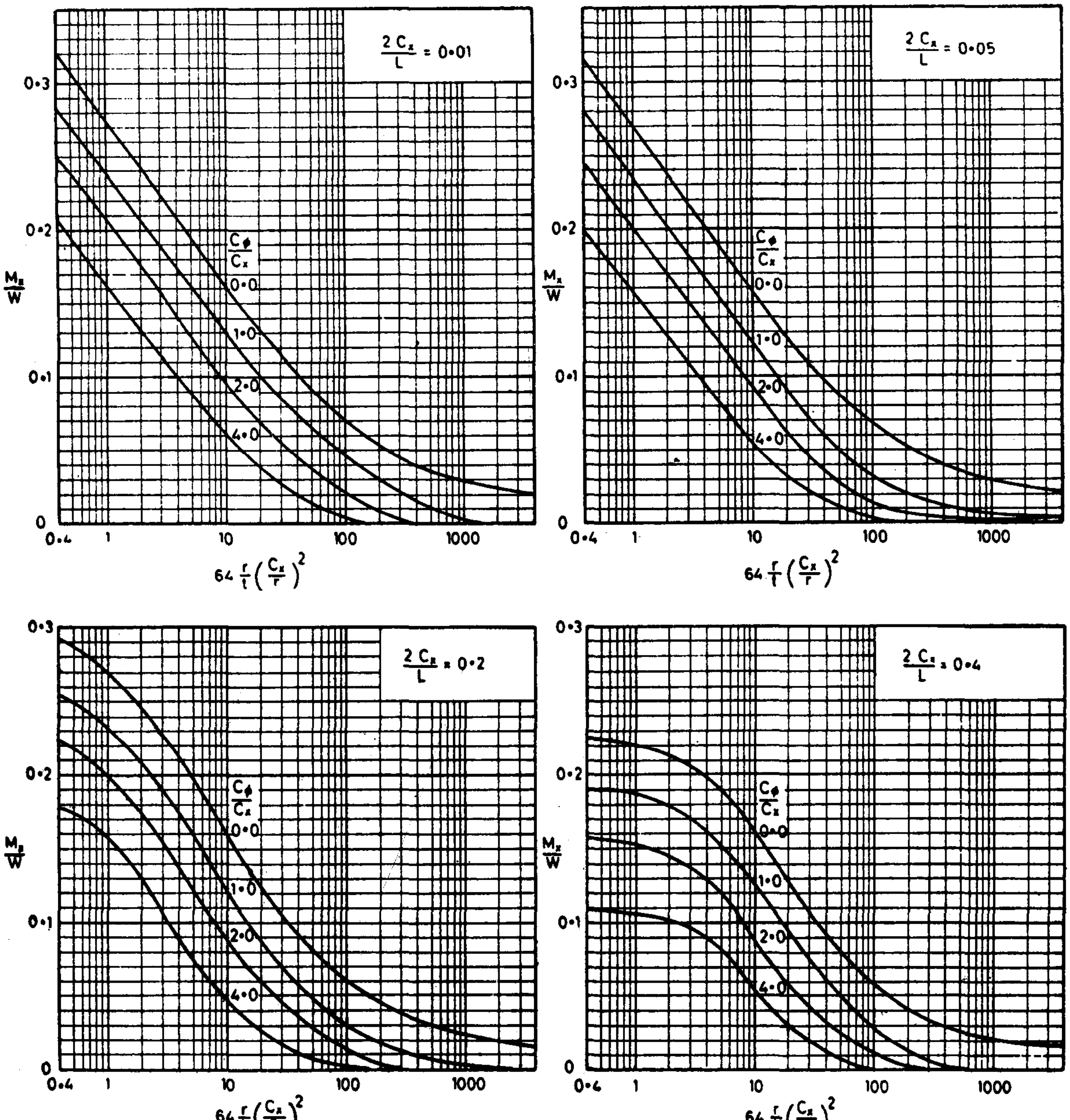
FIG. C.5 CIRCUMFERENTIAL MOMENT PER mm WIDTH

Diagrams for hoop bending moments and forces are printed up the page to distinguish them from those for longitudinal moments and forces which are printed across the page.

When the centre of the load is away from the mid-length of the cylinder, the equivalent length L_e, found as in **C-3.2.1**, should be substituted for L in all cases.

C-3.2.2.2 *Variation of stress along the cylinder* — Consider a radial line load, W, distributed over a length $2C_x$ as shown in Fig. C.13A.

Values of M_ϕ, M_x, N_ϕ and N_x at A can be found from the graphs of Fig. C.13, C.14, C.15 and C.16 respectively.



For explanation *see* **C-3.2.** $64\ \frac{r}{t}\left(\frac{C_x}{r}\right)^2$ is found from Fig. C.4.

M_x = Longitudinal moment per mm width

W = Applied load

C_x = ½ × Axial loading length

C_ϕ = ½ × Circumferential loading length

FIG. C.6 LONGITUDINAL MOMENT PER mm WIDTH

In these charts values of $M\phi/W$, M_x/W, $N\phi t/W$, and $N_x t/W$ are plotted against x/C_x for given values of $64\ r/t(C_x/r)^2$ and $2C_x/L$.

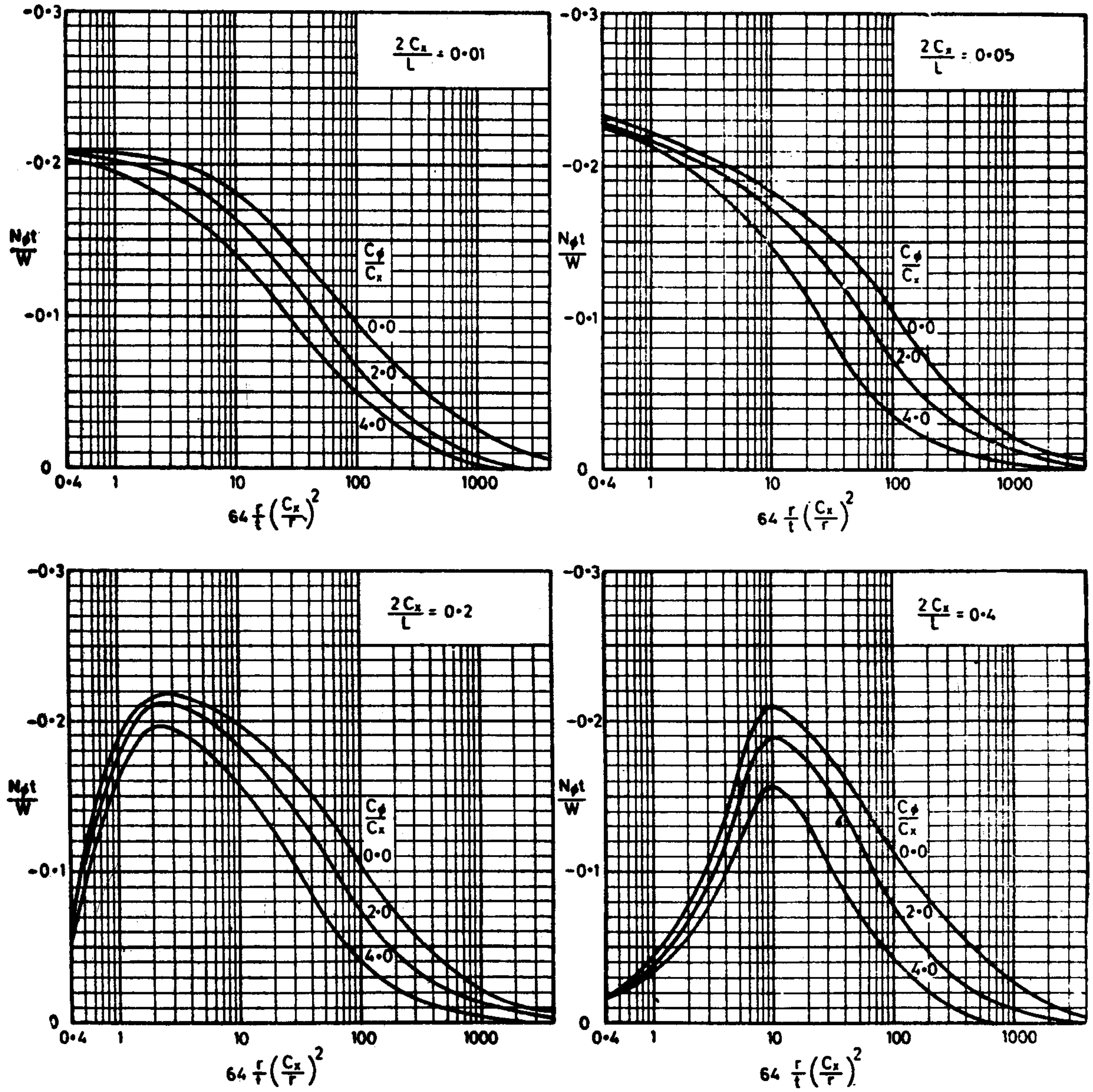
The resultant stresses in the shell at A are given by:

$$\text{Hoop stress } f_\phi = \frac{N_\phi}{t} \pm \frac{6M_\phi}{t^2}$$

$$\text{Longitudinal stress } f_x = \frac{N_x}{t} \pm \frac{6M_x}{t^2}$$

The values for x/C_x less than 1·0, for which no curves are plotted, fall within the loaded lengths, and the curves should not be extended into this region. The values for $x/C_x = 1$ correspond to the maximum stresses found from Fig. C.5, C.6, C.7 and C.8 for $\frac{C_\phi}{C_x} = 0$.

The loading diagram as Fig. C.13A has been repeated on each chart for convenience.



For explanation *see* C-3.2. $64 \times \frac{r}{t} \times \left(\frac{C_x}{r}\right)^2$ is found from Fig. C.4.

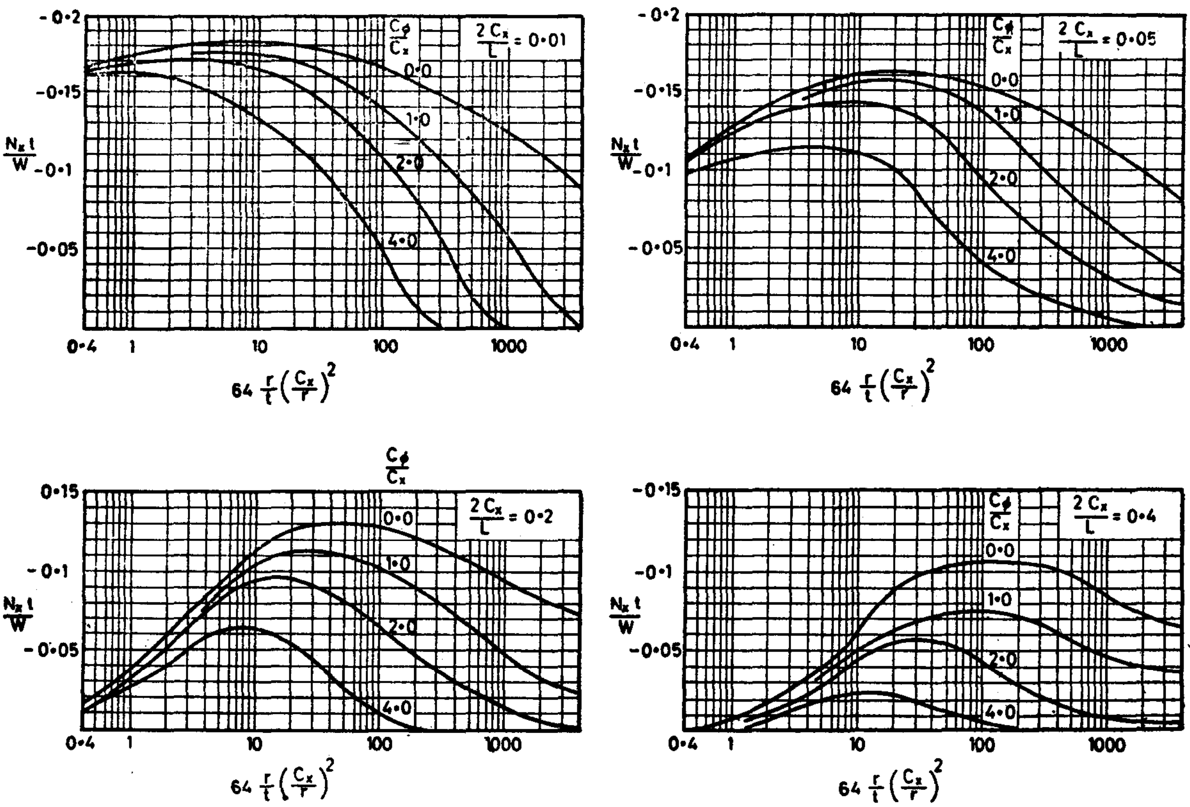
N_ϕ = Circumferential membrane force per mm width

W = Applied load

$C_x = \frac{1}{2} \times$ Axial loading length

$C_\phi = \frac{1}{2} \times$ Circumferential loading length

FIG. C.7 CIRCUMFERENTIAL MEMBRANE FORCE PER mm WIDTH



For explanation *see* **C-3.2.** $64\frac{r}{t}\left(\frac{C_x}{r}\right)^2$ is found from Fig. C.4.

N_x = Longitudinal membrane force per mm width $\quad$ $C_x = \frac{1}{2}$ × Axial loading length

W = Applied load $\quad$ $C_\phi = \frac{1}{2}$ × Circumferential loading length

FIG. C.8 LONGITUDINAL MEMBRANE FORCE PER mm WIDTH

Diagrams for hoop bending moments and forces are printed up the page to distinguish them from those for longitudinal moments and forces which are printed across the page.

For a load distributed over an area $2C_x \times 2C_\phi$ the moments and membrane forces at any value of x/C_x are reduced in the same ratio as the corresponding values at the edge of the load found from Fig. C.5, C.6, C.7 and C.8 in the ratio:

$$\frac{\text{Value for actual } C_\phi/C_x}{\text{Value for } C_\phi/C_x = 0}$$

Example:

A vessel is 2 540 mm diameter × 6·096 m long × 12·7 mm thick.

A radial load W is applied to an area 304·8 mm × 304·8 mm at the mid-length of the shell. Find the circumferential moment at a position 609·6 mm from the centre of the loaded area measured along the axis of the vessel.

$C_\phi = C_x = 152{\cdot}4$ mm; $r = 1\,270$ mm; $r/t = 100$; $C_x/r = 0{\cdot}12$;

$$2C_x/L = \frac{2\times 152{\cdot}4}{609{\cdot}6} = 0{\cdot}05; x/C_x = \frac{609{\cdot}6}{152{\cdot}4} = 4;$$

$$64\frac{r}{t}\left(\frac{C_x}{r}\right)^2 = 90.$$

For a line load, interpolating in Fig. C.13 $M_\phi/W = 0{\cdot}054$ at $x/C_x = 4$.

From Fig. C.5, at the ends of a line load when

$C_\phi/C_x = 0$; $64\ r/t\ (C_x/r)^2 = 90$;

$2\ C_x/L = 0{\cdot}05$

$M_\phi/W = 0{\cdot}153$ and when $C_\phi/C_x = 1{\cdot}0$

$M_\phi/W = 0{\cdot}072$

when the load is distributed over an area 304·8 mm × 304·8 mm

$$M_\phi/W \text{ at } x = 0{\cdot}054 \times \frac{0{\cdot}072}{0{\cdot}153} = 0{\cdot}025$$

Therefore, the circumferential moment at $x = 0{\cdot}025\ W$.

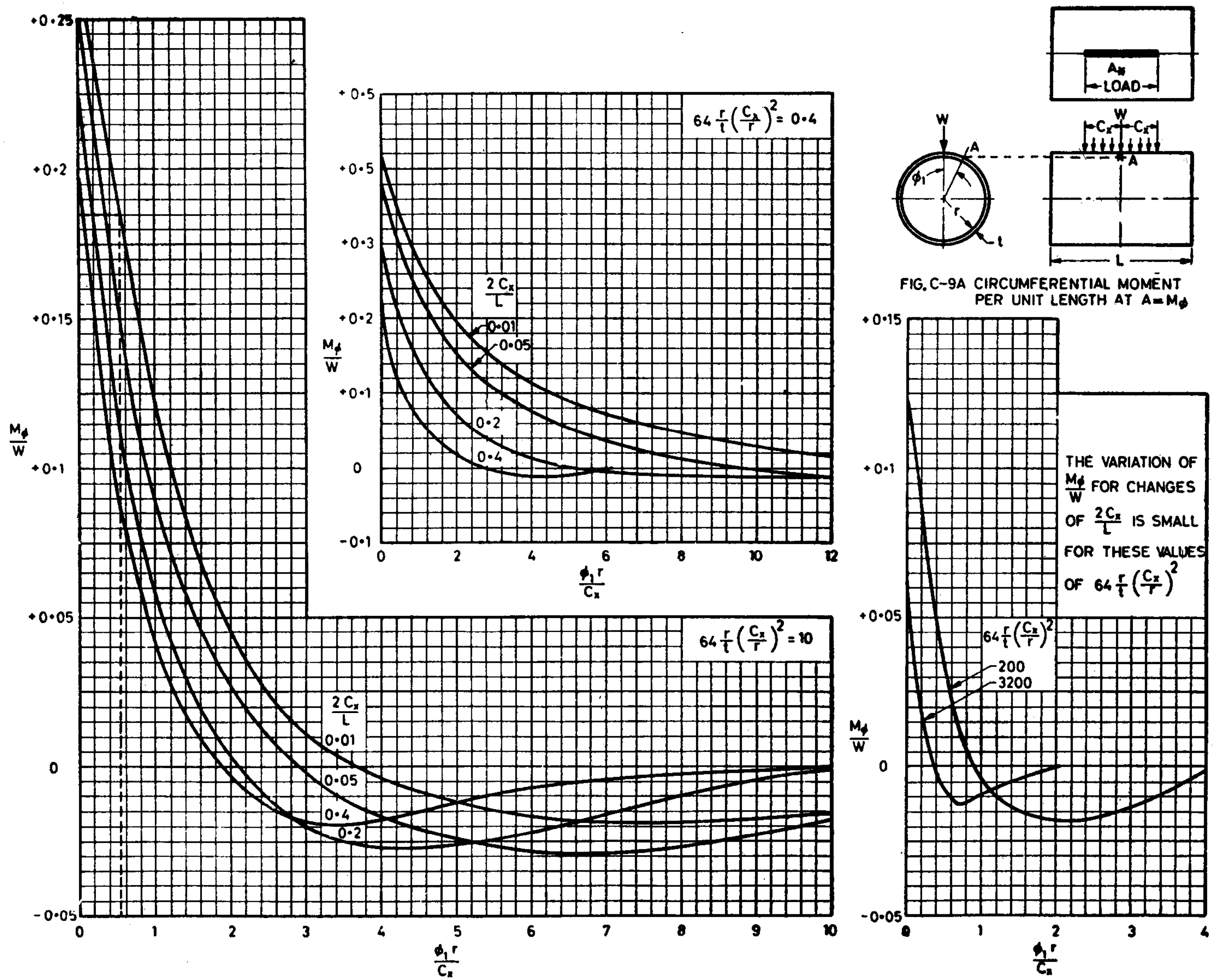


Fig. C.9 Hoop Bending Moment Due to a Radial Line Load Variation Round Circumference

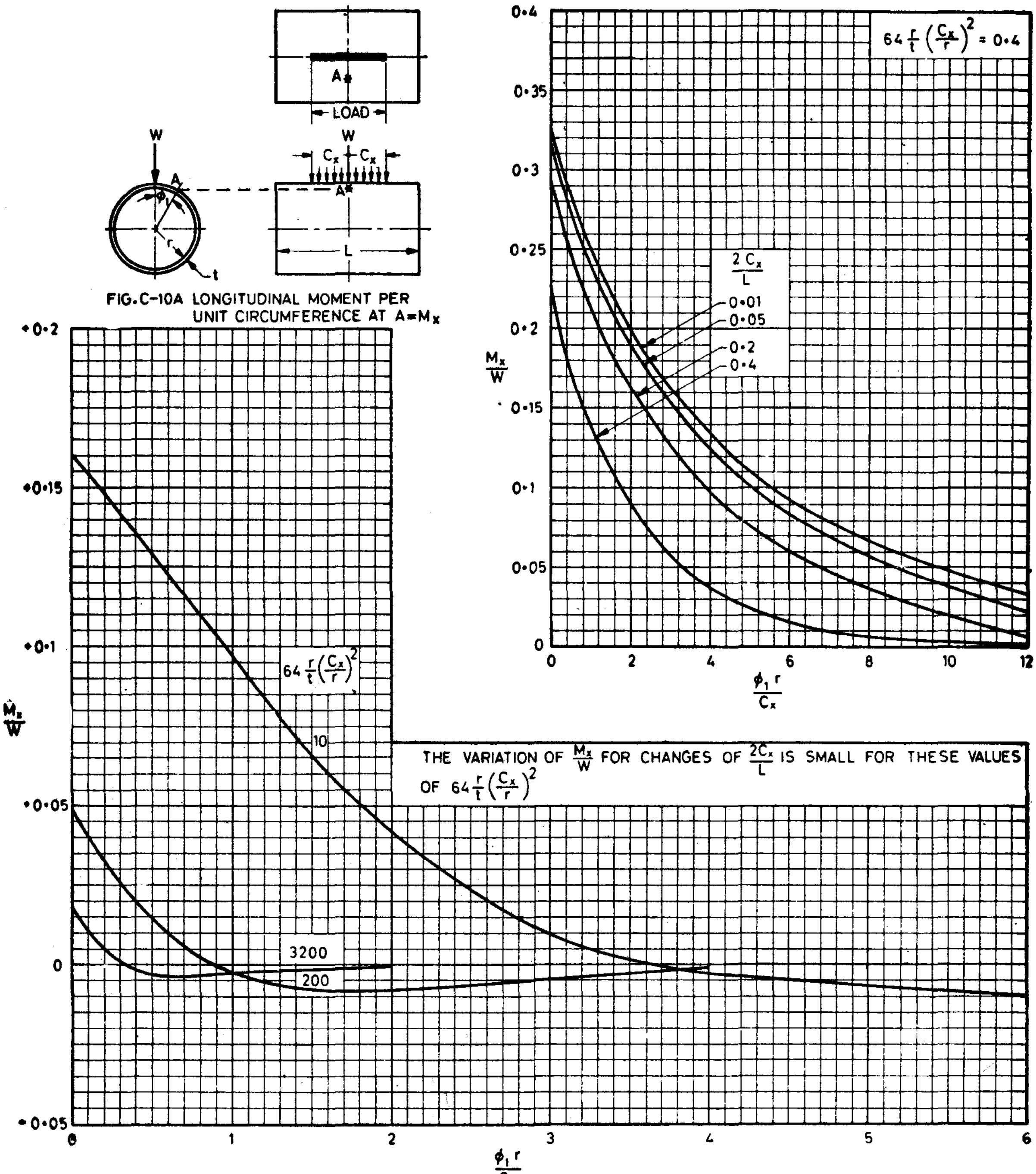
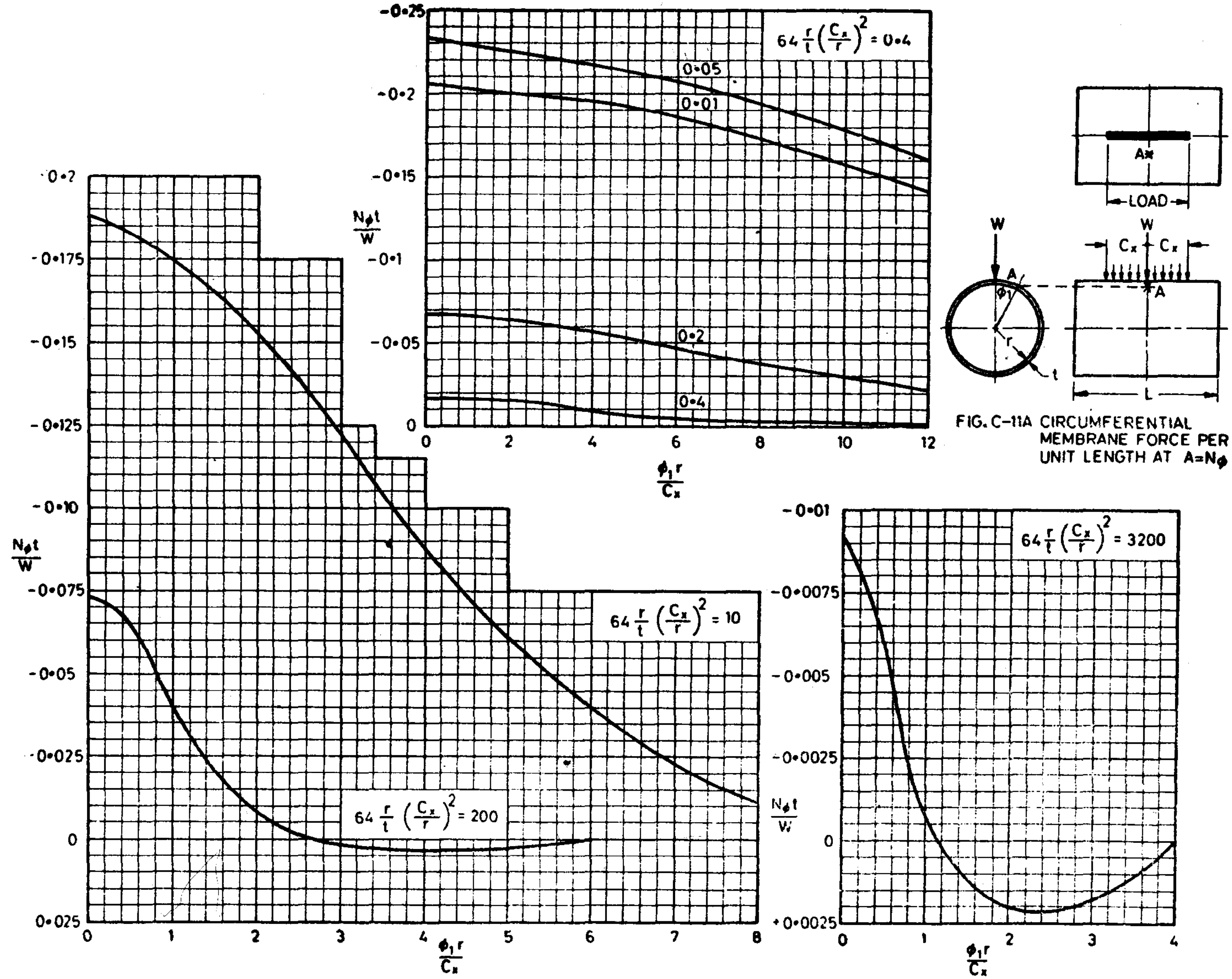


Fig. C.10 Longitudinal Moment from Radial Line Load Variation Round Circumference



The variation of $\frac{N\phi t}{W}$ for changes in $\frac{2C_x}{L}$ is small for the higher values of $64 \frac{r}{t} \left(\frac{C_x}{r}\right)^2$.

FIG. C.11 CIRCUMFERENTIAL MEMBRANE STRESS FROM RADIAL LINE LOAD VARIATION ROUND CIRCUMFERENCE

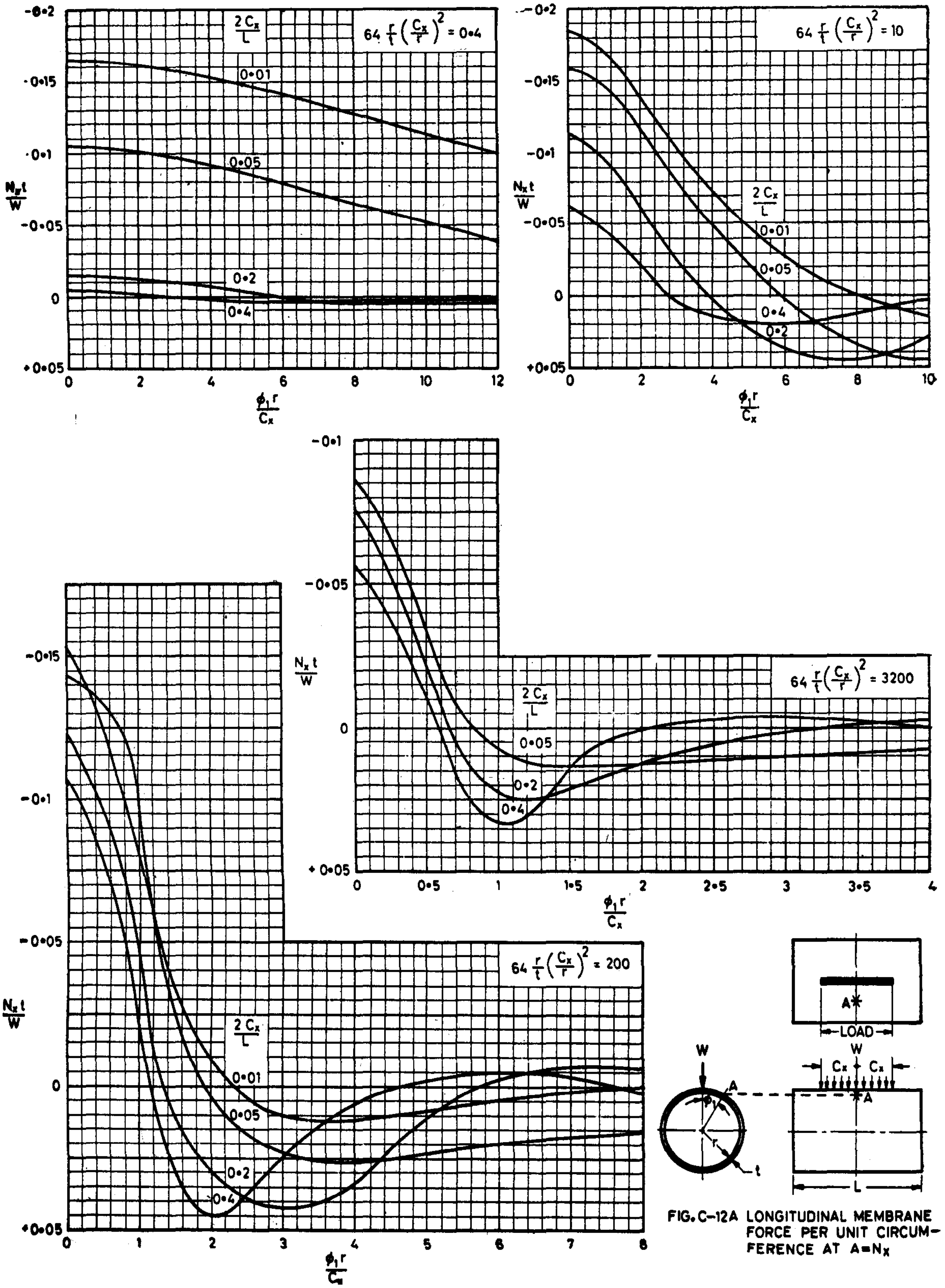


Fig. C.12 Longitudinal Membrane Forces from Radial Line Load Variation Round Circumference

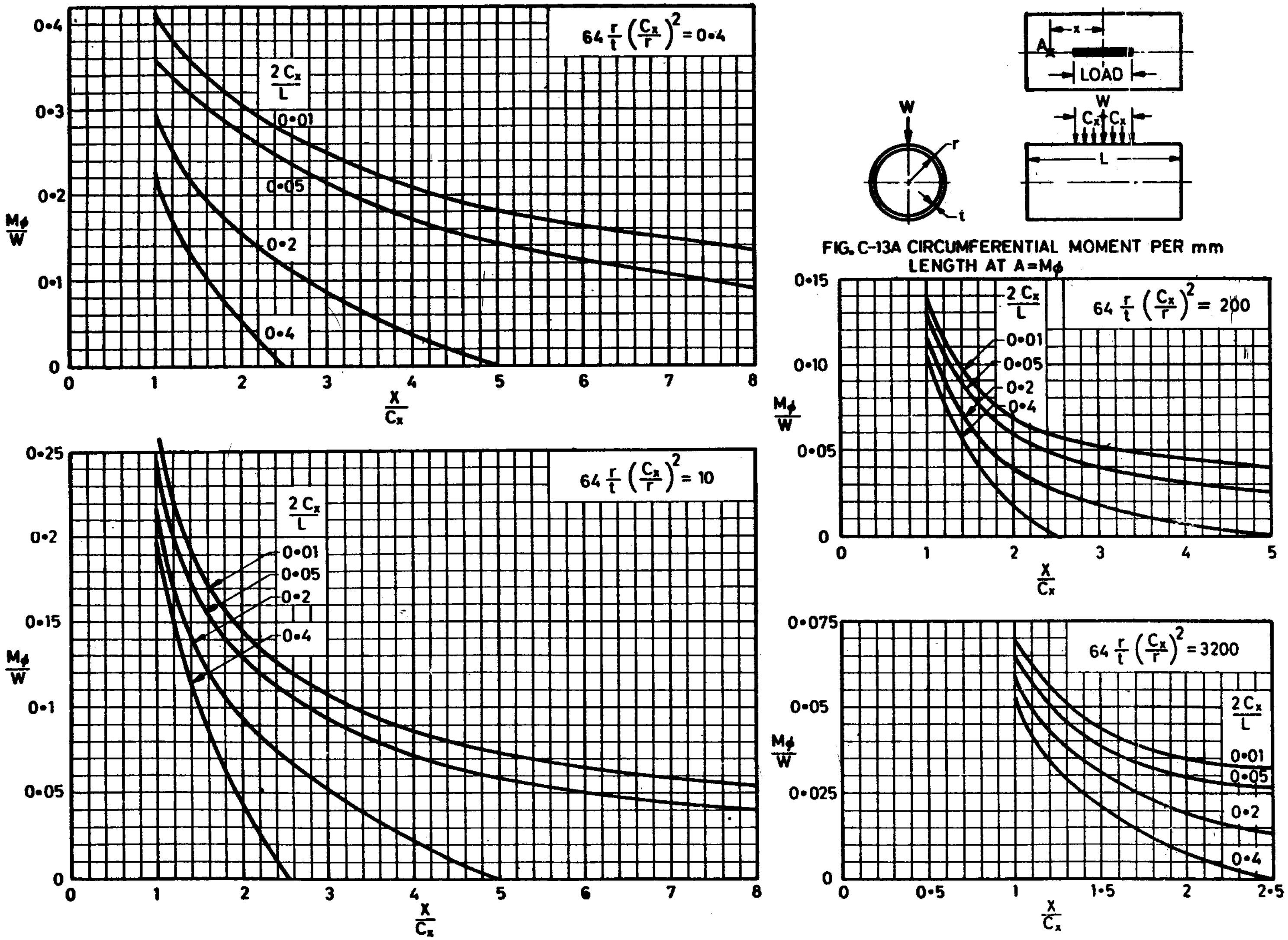


FIG. C.13 HOOP BENDING MOMENT DUE TO A RADIAL LINE LOAD VARIATION ALONG CYLINDER

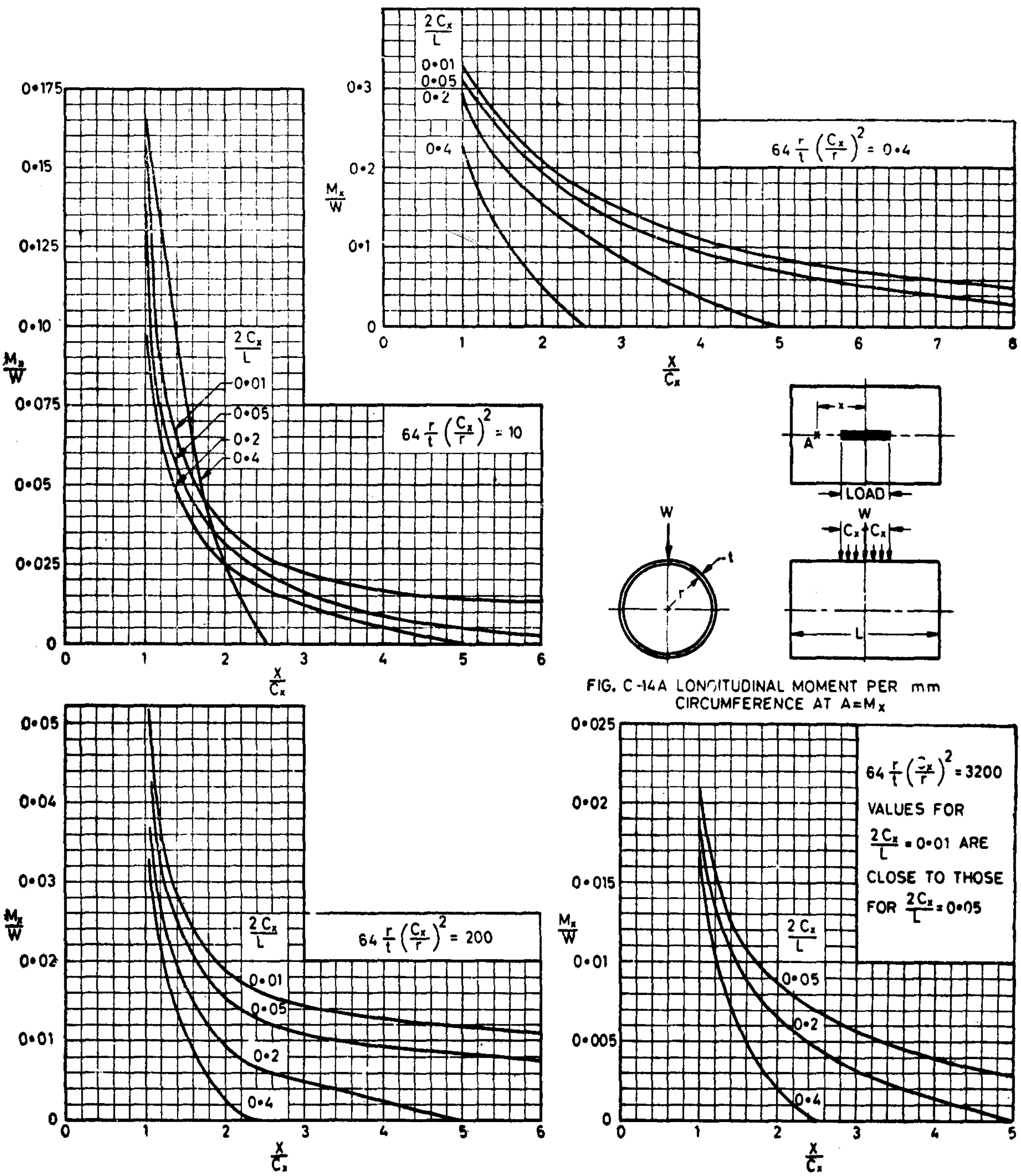


FIG. C.14 LONGITUDINAL MOMENTS DUE TO A RADIAL LINE LOAD VARIATION ALONG CYLINDER

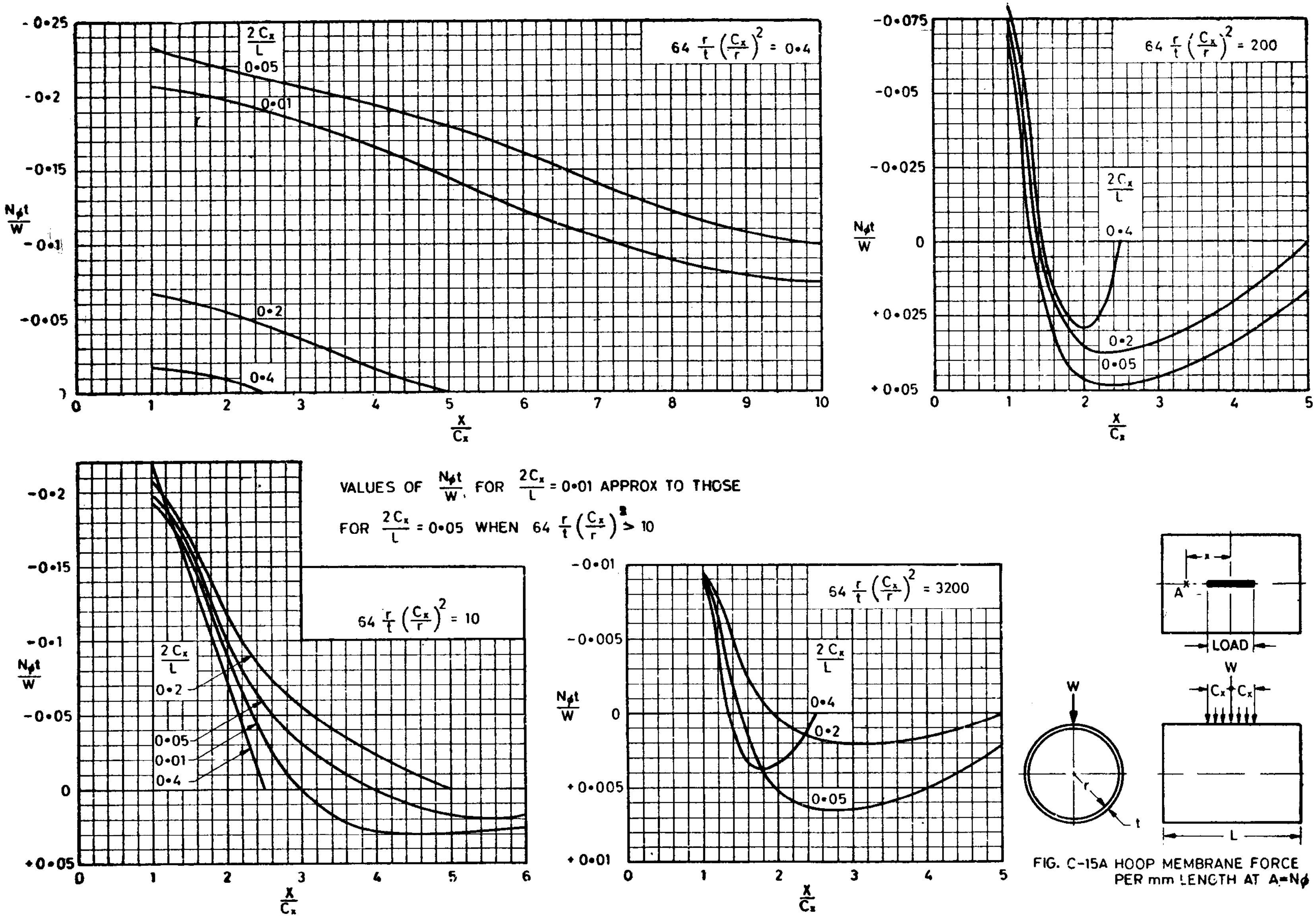


Fig. C.15 Hoop Membrane Forces Due to a Radial Line Load Variation Along Cylinder

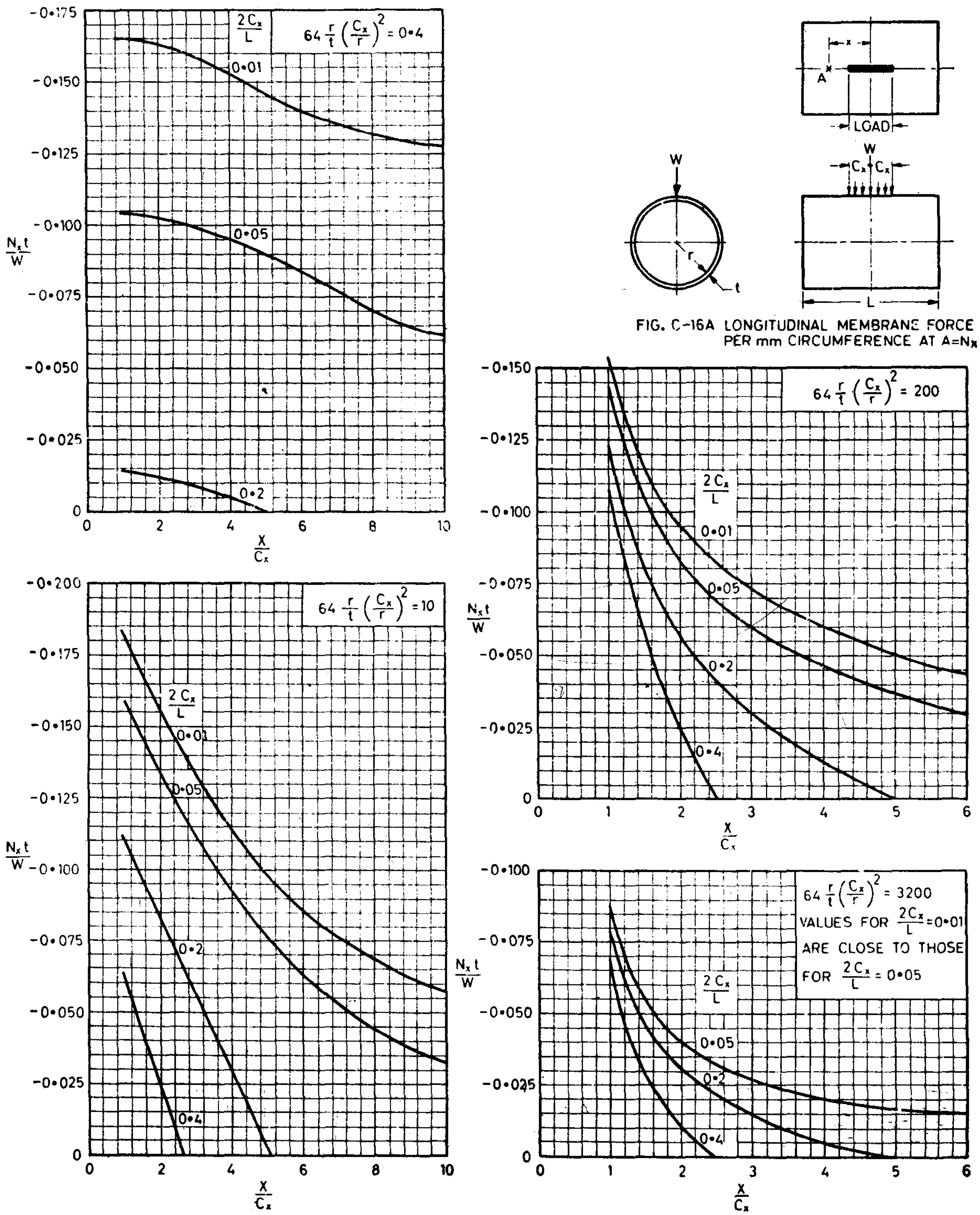


FIG. C.16 LONGITUDINAL MEMBRANE FORCES DUE TO A RADIAL LINE LOAD VARIATION ALONG CYLINDER

C-3.2.3 *The Deflections of Cylindrical Shells Due to Radial Loads* — The deflections of a cylindrical shell due to a local radial load are required for:

a) finding the movement of a vessel shell due to the thrust of a pipe connected to it, and

b) finding the rotation of a branch due to a moment applied by a pipe connected to it (*see* **C-3.3**).

The deflection of the shell due to a radial load is a function of the non-dimensional parameters r/t, $\frac{Er\,\delta}{W}$ and L/r which is given by the full lines in the charts as follows:

Fig. C.17A for values of r/t between 15 and 40.

Fig. C.17B for values of r/t between 40 and 100.

Fig. C.18 for values of r/t greater than 100.

For a central load, L is the actual length of the vessel. For a load out of centre, L is the equivalent length L_e found as in **C-3.2.1**.

For a point load, the value of $\frac{E.r\,\delta}{W}$ is given by the full line from the appropriate horizontal L/r line in the top right-hand extension of each diagram as in the example with Fig. C.17.

For a load distributed over a square of side $2C$, the value of $\frac{\delta\,Er}{W}$ is given by a line joining the intersections of the L/r and C/r lines in the top right-hand and bottom left-hand extensions of each diagram as shown by the dotted line and example on Fig. C.18.

The deflection due to a load distributed over a circular area of radius r_0 is approximately the same as that for a square of side $1{\cdot}7r_0$.

The deflection due to load distributed over a rectangular area $2C_x \times 2C_\phi$ is approximately the same as that for an equivalent square of side $2C_1$ where C_1 is obtained as follows:

$$C_1 = \sqrt{C_\phi\,C_x} \text{ when } C_x > C_\phi \qquad \ldots \quad (\text{C.4})$$

$$C_1 = (C_\phi)^{0{\cdot}93} \times (C_x)^{0{\cdot}07} \text{ when } C_\phi > C_x \ldots \quad (\text{C.5})$$

Equation (C.4) applies to a rectangular area in which the long axis is parallel to the axis of the cylinder.

Equation (C.5) applies to a rectangular area in which the long axis is circumferential.

C-3.3 External Moments Applied to Cylindrical Shells — External moments can be applied to the shell of a vessel by the pipework connected to a branch, by a load on a bracket, or by the reaction at a bracket support.

For design purposes external moments are considered as follows.

C-3.3.1 *Circumferential Moments* — A circumferential moment applied to a rectangular area $C_\theta \times 2C_x$ (*see* Fig. C.20) is resolved into two opposed loads $\pm W = \frac{1{\cdot}5\,M}{C_\theta}$ acting on rectangles of sides $2C_\phi \times 2C_x$, where $C_\phi = \frac{C_\theta}{6}$, which are separated by a distance of $\frac{2C_\theta}{3}$ between centres. For a round branch $C_\theta = 1{\cdot}7\,r_o = 2C_x$.

C-3.3.2 *Longitudinal Moments* — Similarly a longitudinal moment, applied to an area $2C_\phi \times C_z$ (*see* Fig. C.21) is resolved into two opposed loads $\pm W = \frac{1{\cdot}5\,M}{C_z}$ acting on rectangles of sides $2C_\phi \times 2C_x$ where $C_x = \frac{C_z}{6}$, which are separated by a distance of $\frac{2C_z}{3}$ between centres. For a round branch $C_z = 1{\cdot}7r_o = 2C_\phi$.

C-3.3.3 *Maximum Stresses* — The maximum stresses due to the moment occur at the outer edges of the actual loaded area. The circumferential and longitudinal moments and membrane forces are given by:

$$M_\phi = M_{\phi_1} - M_{\phi_2}$$
$$M_x = M_{x1} - M_{x2}$$
$$N_\phi = N_{\phi 1} - N_{\phi_2}$$
$$N_x = N_{x1} - N_{x2}$$

The quantities with subscript 1 are equal to those for a load W distributed over an area of $2C_\phi \times 2C_x$ and are found from Fig. C.5, C.6, C.7 and C.8.

Those with subscript 2 are equal to those due to a similar load at a distance $x = 5C_x$ from the centre of the loaded area for a longitudinal moment or at an angle of $\phi_1 = \frac{5C_\phi}{r}$ from the radius through the centre of the loaded area for a circumferential moment. These can be neglected if the value of K_2, from Table C.3, corresponding to the value of $2C_x/L$ for a longitudinal moment, or that of K_1 corresponding to the value of $2C_x/L$ for a circumferential moment, is less than 5·0. Otherwise they are found as follows:

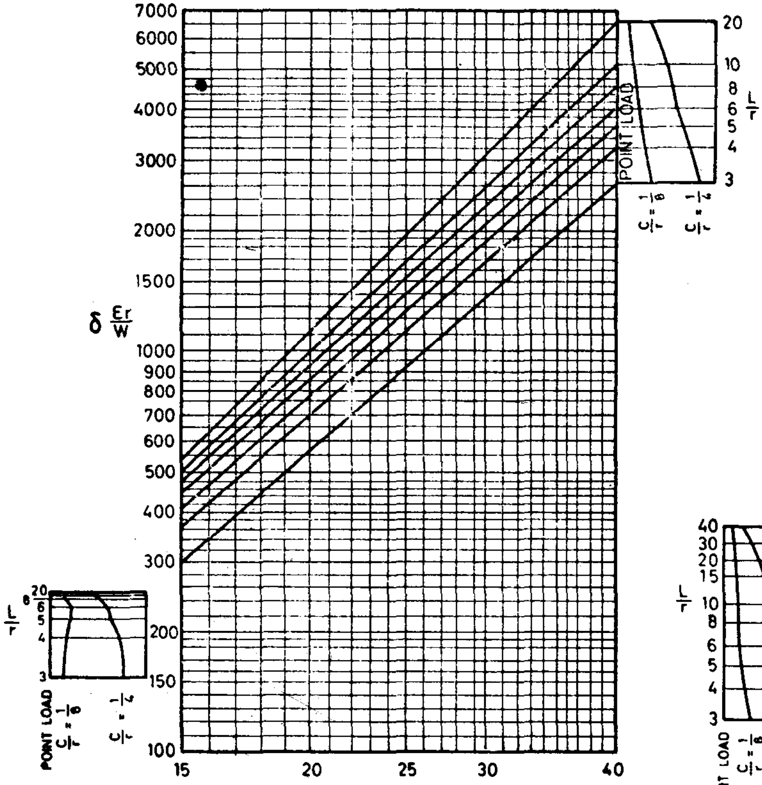
For a longitudinal moment:

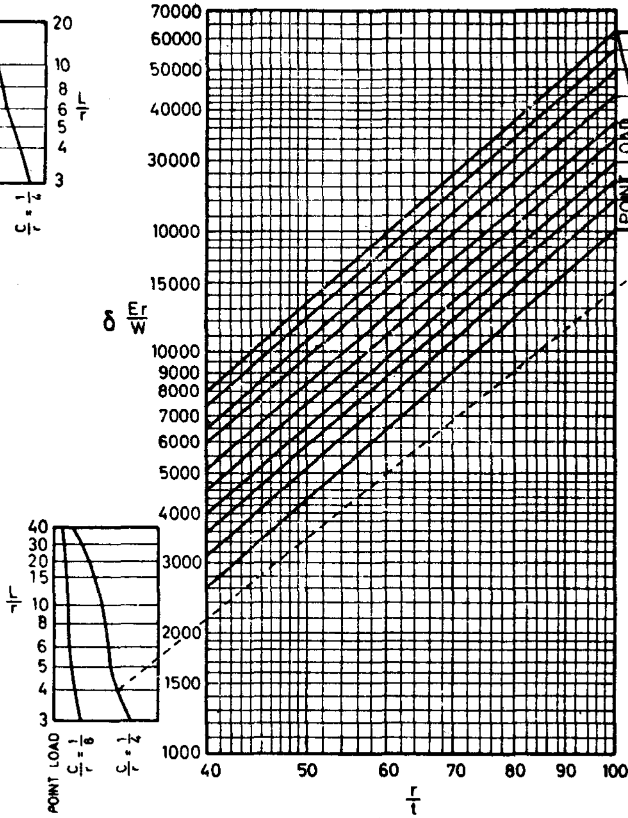
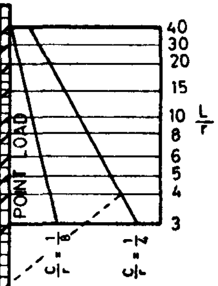
a) Take $x/C_x = 5{\cdot}0$ and obtain values for a radial line load from Fig. C.13, C.14, C.15 and C.16. It may be necessary to use different values of L_e (*see* **C-3.2.1**) for the two resolved loads if the moment is distributed over an area which is *not* small compared to its distance from the nearer end of the vessel.

b) Correct these values for a total circumferential width equal to $2C_\phi$ as in example in **C-3.2.2.2**.

For a circumferential moment:

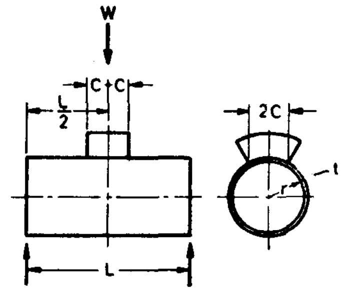
a) Find the values at the edge of the loading area $2C_\phi \times 2C_x$ from Fig. C.5, C.6, C.7 and C.8.



C.17A For r/t Less Than 40

C.17B For r/t Between 40 and 100



C.17C

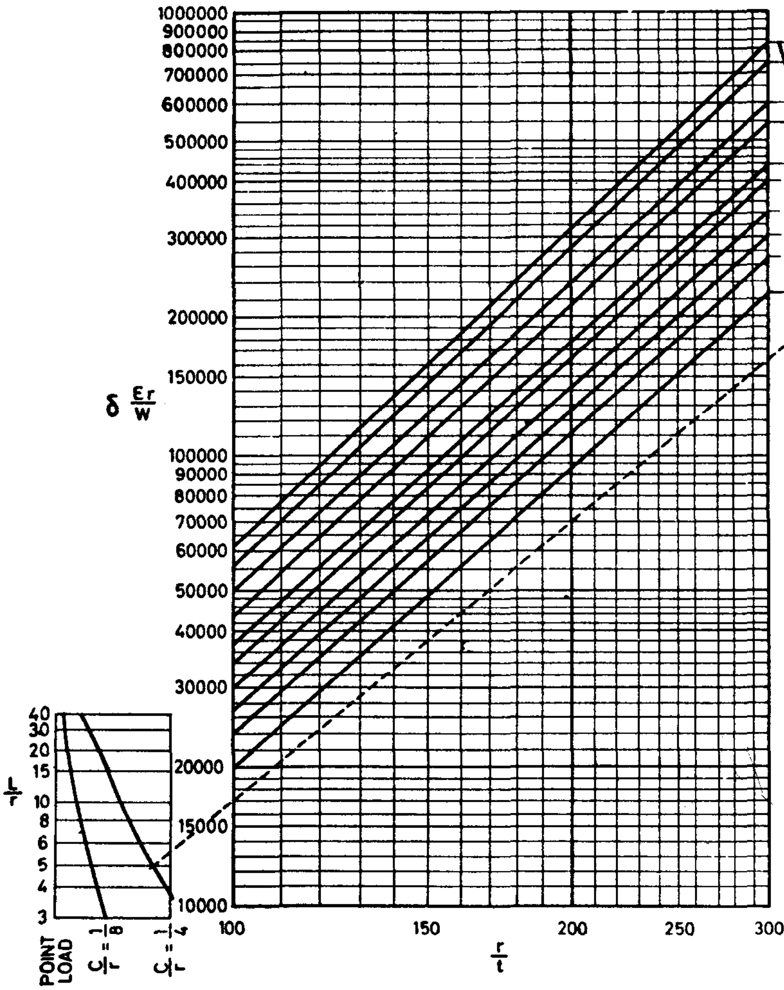
Example:

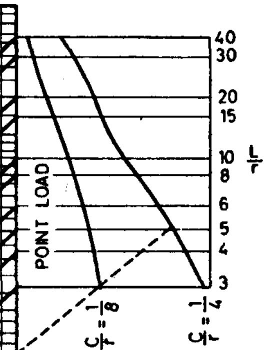
Find $\delta \frac{Er}{W}$ for $L/r = 10$, $r/t = 70$, $C/r = 0$ = point load. Enter $L/r = 10$ at right-hand side of chart, move horizontally to $C/r = 0$ or point load, proceed down sloping line to meet vertical line for $r/t = 70$, then move horizontally and read $\delta \frac{Er}{W} = 17\ 000$.

For values of r/t greater than 100, *see* Fig. C.18.

Values of δ are exclusive of the deflection of the whole shell as a beam.

FIG. C.17 MAXIMUM RADIAL DEFLECTION OF A CYLINDRICAL SHELL SUBJECTED TO A RADIAL LOAD W UNIFORMLY DISTRIBUTED OVER A SQUARE $2C \times 2C$





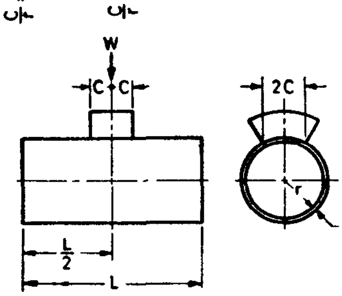


FIG. C-18A

Example:

Find $\delta \frac{Er}{W}$ for $L/r = 5$, $C/r = \frac{1}{4}$, $r/t = 180$. Enter L/r at 5 at both sides of chart, move horizontally to $C/r = \frac{1}{4}$. Join intersection points. Enter r/t at 180. Move vertically to intersection line and then move horizontally and read $\delta \frac{Er}{W} = 55\,000$.

For values of r/t less than 100, *see* Fig. C.17.

Values of δ are exclusive of the deflection of the whole shell as a beam.

FIG. C.18 MAXIMUM RADIAL DEFLECTION OF A CYLINDRICAL SHELL SUBJECTED TO A RADIAL LOAD W UNIFORMLY DISTRIBUTED OVER A SQUARE $2C \times 2C$

b) Enter the corresponding graph in Fig. C.9, C.10, C.11 and C.12 at this value. The intercept on the curve for $2C_x/L$ gives a value of:

$$\frac{\phi_1 r}{C_x} = Z.$$

c) The values for quantities with subscript 2 are then given by the ordinate for

$\frac{\phi_1 r}{C_x} = \frac{5C_\phi}{C_x} - Z$ from the same graph.

C-3.3.4 *Rotation Due to External Moments* — It is sometimes required to find the rotation of a branch or bracket due to a moment applied to it. This is given approximately by $i = \frac{3\,\delta_1}{C_\theta}$ for a circumferential moment or $i = \frac{3\,\delta_1}{C_z}$ for a longitudinal moment, where δ_1 is the deflection produced by one of the equivalent loads $W = \frac{1{\cdot}5\,M}{C_\theta}$ or $\frac{1{\cdot}5\,M}{C_z}$ acting on an area of $2C_\phi \times 2C_x$ as defined in Fig. C.20 or C.21. δ_1 is found from Fig. C.17 and C.18.

Example:

A vessel is 2 540 mm diameter $\times$ 4 064 mm long $\times$ 12·7 mm thick. Find the maximum stress due to a longitudinal moment of 115 454 kgf mm applied to a branch 356 mm

diameter at the mid-length, and the slope of the branch.

$$C_\phi = \frac{C_z}{2} = 0{\cdot}85 \times 356/2 \simeq 152$$

$$W = \pm \frac{1{\cdot}5\,M}{C_z} = \pm \frac{1{\cdot}5 \times 115\,454}{152 \times 2} = \pm\ 567 \text{ kg}$$

W acts on an area $2C_\phi \times 2C_x$,

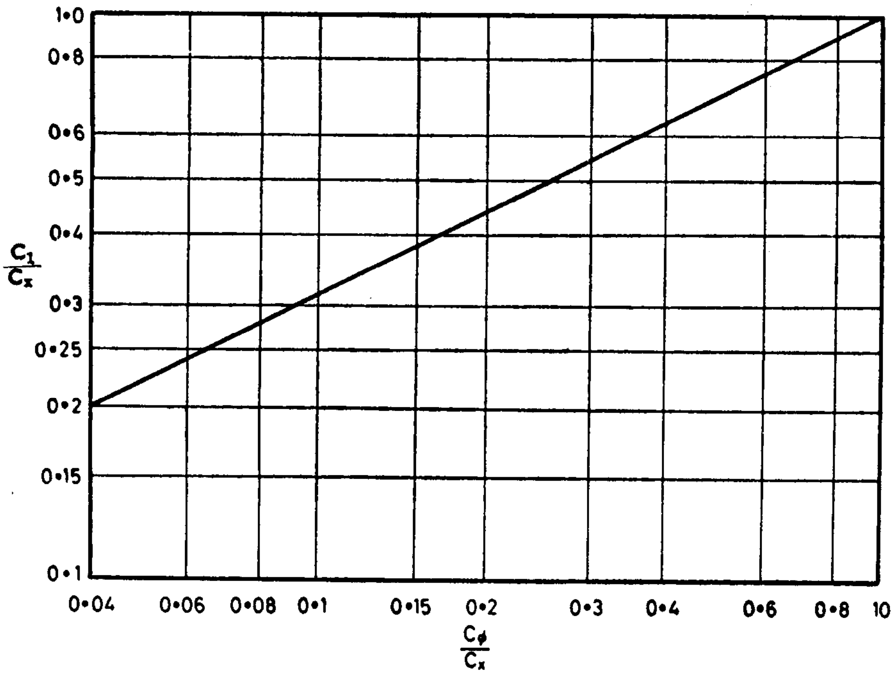
where $C_x = \dfrac{C_z}{6} = 50{\cdot}8$ mm

For this area : $\dfrac{C_\phi}{C_x} = \dfrac{152}{50{\cdot}8} = 3$;

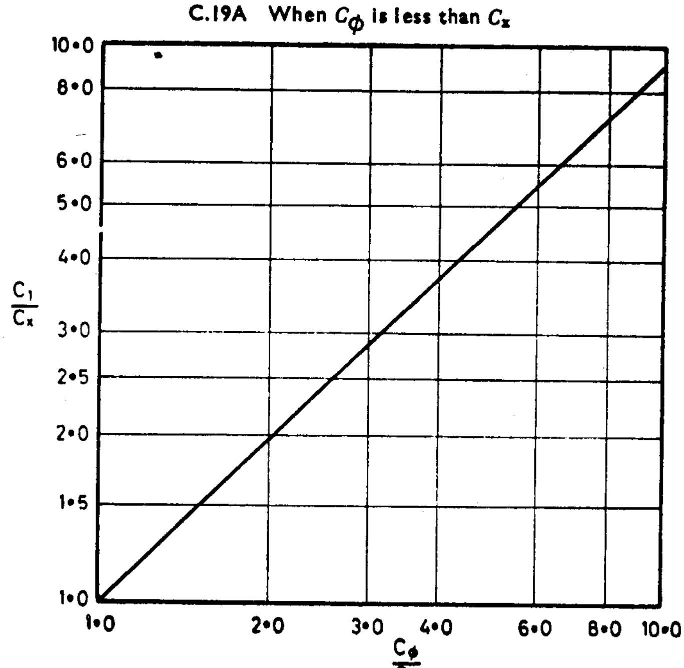
$$\frac{C_x}{r} = \frac{50{\cdot}8}{1\,270} = 0{\cdot}04;$$

$$\frac{2C_x}{L} = \frac{2 \times 50{\cdot}8}{4\,064} = 0{\cdot}025$$

From Fig. C.4, $64\,\dfrac{r}{t}\left(\dfrac{C_x}{r}\right)^2 \simeq 10.$



C.19A When C_ϕ is less than C_x



C.19B When C_ϕ is greater than C_x

FIG. C.19 GRAPHS FOR FINDING THE SQUARE $2C_1 \times 2C_1$ EQUIVALENT TO A RECTANGULAR LOADING AREA $2C_x \times 2C_\phi$

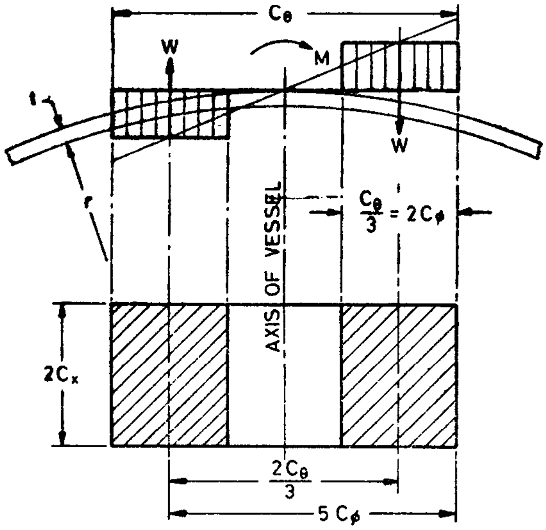


FIG. C.20 CIRCUMFERENTIAL MOMENT

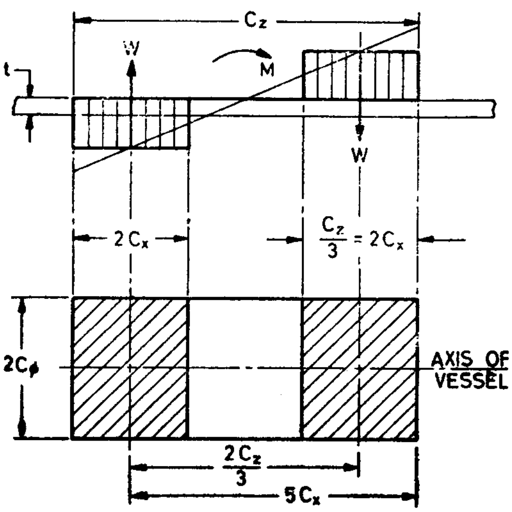


FIG. C.21 LONGITUDINAL MOMENT

The direct effect of each load W is found by interpolating for $C_\phi/C_x = 3{\cdot}0$ in the charts of Fig. C.5, C.6, C.7 and C.8 for $2C_x/L = 0{\cdot}025$ which gives:

$$M_{\phi_1}/W = 0{\cdot}09; \ M_{x1}/W = 0{\cdot}076$$
$$N_{\phi_1}t/W = -0{\cdot}155$$
$$N_{x1}t/W = -0{\cdot}14$$

The effect of one load at the outer edge of the other is found by interpolating for $64\frac{r}{t}\left(\frac{C_x}{r}\right)^2 = 10$, $x/C_x = 5{\cdot}0$ and $2C_x/L = 0{\cdot}025$ in the charts of Fig. C.13, C.14, C.15 and C.16 for a radial line load, and multiplying the results by a correction factor for the circumferential width of the load as in **C-3.2.2.2**.

The values interpolated from Fig. C.13 to C.16 denoted by subscript 3, are:

$$M_{\phi_3}/W = 0{\cdot}065; \ M_{x3}/W = 0{\cdot}012$$
$$N_{\phi_3}t/W = +0{\cdot}025$$
$$N_{x3}t/W = -0{\cdot}085$$

Quantity	*Values for* $C_\phi/C_x = 0$	*Figure*	*Correction factor* $= \frac{\text{value for } C\phi/C_x = 3}{\text{Value for } C\phi/C_x = 0}$
$\frac{M_{\phi 3}}{W}$	0·255	C.5	$\frac{0{\cdot}09}{0{\cdot}255} = 0{\cdot}353$
$\frac{M_{x3}}{W}$	0·16	C.6	$\frac{0{\cdot}076}{0{\cdot}16} = 0{\cdot}475$
$N_{\phi_3}t/W$	0·18	C.7	$\frac{-0{\cdot}155}{-0{\cdot}18} = 0{\cdot}861$
$N_{x3}t/W$	0·17	C.8	$\frac{-0{\cdot}14}{-0{\cdot}17} = 0{\cdot}824$

Hence $\frac{M_{\phi 2}}{W} = +0{\cdot}065 \times 0\ 353 = 0{\cdot}023$

$$N_{\phi_3}t/W = +0{\cdot}025 \times 0{\cdot}861 = 0{\cdot}021\ 5$$

$$\frac{M_{x2}}{W} = +0{\cdot}012 \times 0{\cdot}475 = 0{\cdot}005$$

$$\frac{N_{x2}t}{W} = -0{\cdot}085 \times 0{\cdot}824 = -0{\cdot}070$$

$$M_\phi = W\left[\frac{M_{\phi 1}}{W} - \frac{M_{\phi 2}}{W}\right]$$
$$= 567\ (0{\cdot}09 - 0{\cdot}023)$$
$$= 567 \times 0{\cdot}067 = 38{\cdot}7 \text{ kgf·mm/mm}$$

$$M_x = W\left[\frac{M_{x1}}{W} - \frac{M_{x2}}{W}\right]$$
$$= 567\ (0{\cdot}076 - 0{\cdot}005\ 7)$$
$$= 567 \times 0{\cdot}070\ 3 = 39{\cdot}8 \text{ kgf·mm/mm}$$

$$N_\phi = \frac{W}{t}\left(N_{\phi 1}t/W - N_{\phi 2}t/W\right)$$
$$= \frac{567}{12{\cdot}7}\ (-0{\cdot}155 - 0{\cdot}021\ 5)$$
$$= \frac{567}{12{\cdot}7} \times (-0{\cdot}176\ 5)$$
$$= -7{\cdot}88 \text{ kgf/mm}$$

$$N_x = \frac{W}{t}\left[\frac{N_{x1}t}{W} - \frac{N_{x2}t}{W}\right]$$
$$= \frac{567}{12{\cdot}7}\ (-0{\cdot}14 + 0{\cdot}07)$$
$$= -3{\cdot}12 \text{ kgf/mm;}$$

$\therefore$ Maximum hoop stress

$$= f_\phi = \frac{N_\phi}{t} + \frac{6M_\phi}{t^2}$$
$$\therefore f_\phi = -\frac{7{\cdot}88}{12{\cdot}7} \pm \frac{6 \times 38{\cdot}7}{12{\cdot}7 \times 12{\cdot}7}$$
$$= -0{\cdot}62 \pm 1{\cdot}44$$

$\therefore$ Maximum hoop compressive stress $= -2{\cdot}06$ kgf/mm²;

Maximum hoop tensile stress $= +0{\cdot}82$ kgf/mm²

Maximum longitudinal stress $= \frac{N_x}{t} \pm \frac{6M_x}{t^2}$

$$\therefore f_x = -\frac{3{\cdot}12}{12{\cdot}7} \pm \frac{6 \times 39{\cdot}8}{12{\cdot}7 \times 12{\cdot}7}$$
$$= -0{\cdot}248 \pm 1{\cdot}48$$

Maximum longitudinal compressive stress = -1.728 kgf/mm²

Maximum longitudinal tensile stress = $+1.232$ kgf/mm²

Slope due to moment: For this area $C_\phi / C_x = 3$, and from Fig. C.19B, the half side of the equivalent square $C_1 = 2.8 C_x = 2.8 \times 50.8 = 142$ mm

In Fig. C.17B, $C_1/r = 142/1\,270 = 0.112$;

$L/r = 4\,064/1\,270 = 3.2$;

$r/t = 1\,270/12.7 = 100$;

whence $\delta Er/W = 17\,000$

$$\therefore \delta_1 = \frac{1.7 \times 10^4 \times 567}{2.04 \times 10^4 \times 1\,270} = 0.372 \text{ mm}$$

and from **C-3.3.4**, the slope $i = \dfrac{3\,\delta_1}{C_z}$

$$= \frac{3 \times 0.372}{304.8}$$

$= 0.003\,66$ radians.

C-3.4 Local Loads on Spherical Shells

C-3.4.1 *Initial Development* — This clause is concerned with the stresses and deflections due to local radial loads or moments on spherical shells. Because these are local in character and die out rapidly with increasing distance from the point of application, the data derived from references 8 and 9 can be applied to local loads on the spherical parts of pressure vessel ends as well as to complete spheres.

For convenience, the loads are considered as acting on a pipe of radius r_0 which is assumed to be a rigid body fixed to the sphere. This is the condition for the majority of practical cases.

Loads applied through square fittings of side $2C_x$ can be treated approximately as distributed over a circle of radius $r_0 = C_x$.

Loads applied through rectangular brackets of sides $2C_x$ and $2C_\phi$ can be treated approximately as distributed over a circle of radius $r_0 = \sqrt{C_x . C_\phi}$.

The following forces and moments are set up in the wall of the vessel by any local load or moment.

a) *Meridional moment* M_x — acting per unit width on a normal section, formed by the intersection of shell with a cone of semi-vertex angle $\phi = \sin^{-1}\dfrac{x}{r}$ (Fig. C.23 and C.26).

b) *Hoop moment* M_ϕ — acting per unit width on a meridional section passing through the axis of the shell and the axis of the branch.

c) *Meridional membrane force* — acting per unit width on a normal section as for the meridional moment M_x.

d) *Hoop membrane force* — acting per unit width on a meridional section as defined for the hoop moment M_ϕ.

A moment is considered as positive if it causes compression at the outside of the vessel.

A membrane force is considered as positive if it causes tension in the vessel wall.

A deflection is considered positive if it is away from the centre of the sphere.

These forces and moments and the deflection of the shell due to the load can be found in terms of the non-dimensional parameters

$$s = \frac{1.82\,x}{\sqrt{rt}}$$

and

$$u = \frac{1.82\,r_0}{\sqrt{rt}}$$

The parameter s defines the position in the shell at which the force, moment, or deflection is required.

The parameter u defines the area over which the load is distributed.

These two factors can be found quickly from the chart in Fig. C.22 given x, r_0 and the ratio r/t.

Figures C.24, C.25, C.27 and C.28 give graphs of non-dimensional functions of the deflection, forces and moments listed above plotted against the parameter s for given values of u which have been derived from References 8 and 9.

The full curves in each set of graphs give conditions at the edge of the loaded area where $u = s$. The most unfavourable combination of bending and direct stresses is usually found here.

The dotted curves for particular values of u give conditions at points in the shell away from the edge of the loaded area where x is greater than r_0 and u is therefore less than s.

Since the charts are in non-dimensional terms they can be used in any consistent system of units.

The stresses and deflections found from these charts will be reduced by the effect of internal pressure but this reduction is small and can usually be neglected in practice. (References 8 and 9.)

C-3.4.2 *Stresses and Deflections Due to Radial Loads* — Figure C.23 shows a radial load applied to a spherical shell through a branch of radius r_0.

The deflections, moments and membrane forces due to the load W can be found as follows from Fig. C.24 and C.25. For explanation of these curves, *see* **C-3.4.3**. For an example of their use, *see* **C-3.4.4**.

a) Deflection; use Fig. C.24 and the relation:

$$\delta = \text{ordinate of curve} \times \frac{W.r}{Et^2}$$

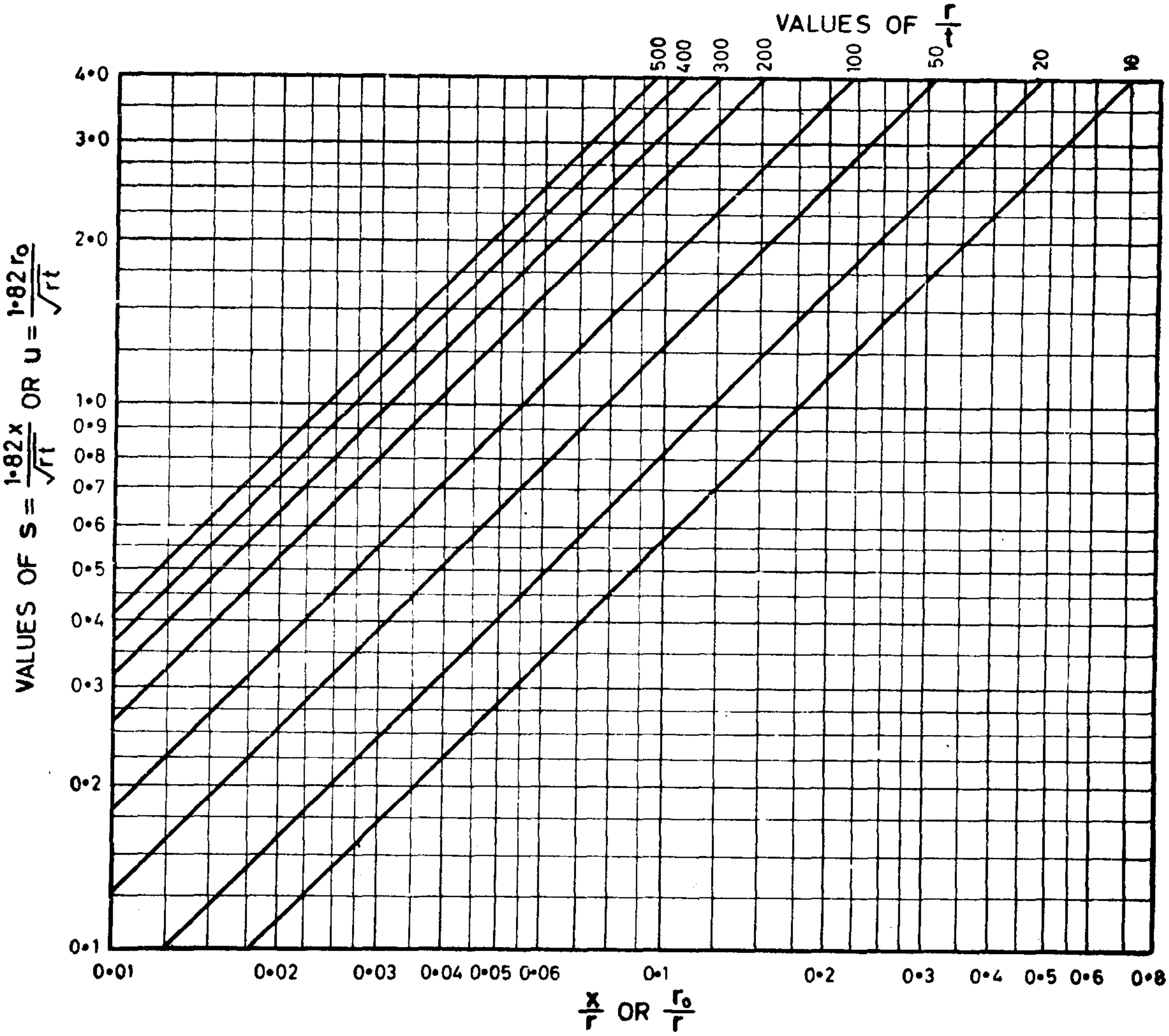


FIG. C.22 CHART FOR FINDING s AND u

b) Meridional moment M_x per unit width from Fig. C.25 and the relation:

M_x = ordinate of M_x curve $\times$ W.

c) Hoop moment M_ϕ per unit width from Fig. C.25 and the relation:

M_ϕ = ordinate of M_ϕ curve $\times$ W.

d) Meridional membrane force N_x per unit width from Fig. C.27 and N_x = ordinate of N_x curve $\times$ W/t.

e) Hoop membrane force N_ϕ per unit width from Fig. C.27 and N_ϕ = ordinate of N_ϕ curve $\times$ W/t.

C-3.4.3 *Stresses, Deflections and Slopes Due to an External Moment* — Figure C.26 shows an external moment applied to a spherical shell through a branch of radius r_0.

In this case the deflections, moments and membrane forces depend on the angle θ as well as on the distance x from the axis of the branch. They can be found as follows from Fig. C.27 and **C.28**. For explanations of these curves *see* **C-3.4.1**.

a) Deflections; use Fig. C.27 and the relation:

$$+\delta = \text{ordinate of curve} \times \frac{M\sqrt{\frac{r}{t}\cos\theta}}{Et^2}$$

b) Meridional moment M_x per unit width; use Fig. C.28 and

$$M_x = \text{ordinate of } M_x \text{ curve} \times \frac{M\cos\theta}{\sqrt{rt}}$$

c) Hoop moment M_ϕ per unit width; use Fig. C.28 and

$$M_\phi = \text{ordinate of } M_\phi \text{ curve} \times \frac{M\cos\theta}{\sqrt{rt}}$$

d) Meridional membrane force per unit width; use Fig. C.28 and

$$N_x = \text{ordinate of } N_x \text{ curve} \times \frac{M\cos\theta}{t.\sqrt{rt}}$$

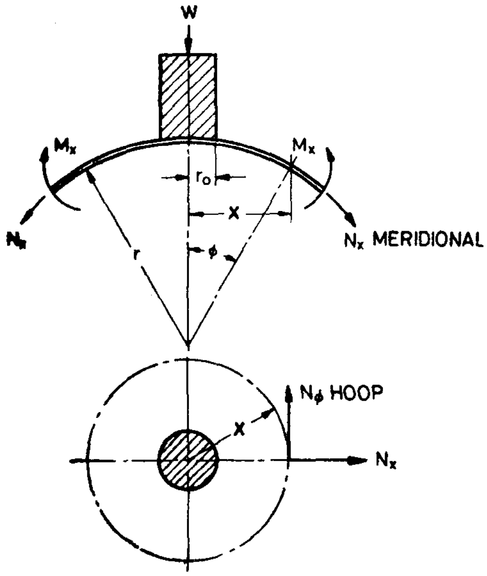


FIG. C.23 RADIAL LOAD APPLIED TO SPHERICAL SHELL

e) Hoop membrane force per unit width; Fig. C.25 and

$$N_\phi = \text{ordinate of } N_\phi \text{ curve} \times \frac{M \cos \theta}{t.\sqrt{rt}}$$

Equal and opposite maximum values of all the above quantities occur in the plane of the moment, that is, where θ (Fig. C.26) = 0° and θ = 180°.

The slope of the branch due to the external moment is found from

$$i_b = \frac{\delta_1}{r_0}$$

where δ_1 is the maximum deflection at the edge of the branch for $\theta = 0$ and $u = s$, that is,

$$\delta_1 = \frac{M\sqrt{\frac{r}{t}}}{Et^2} \times \text{(ordinate of full curve}$$

in Fig. C.27 for $x = r_0$).

C-3.5 The Effect of External Forces and Moments at Branches — Large external forces and moments can be applied to the branches of vessels by the thermal movements of pipework.

The stresses due to these are likely to be greatly overestimated if the forces in the pipe system are determined by assuming that the connection to the vessel is equivalent to an anchor in the pipe system.

More accurate values of the terminal forces and moments can be found if the deflection due to a unit radial load and the slopes due to unit longitudinal and circumferential moments distributed over the area of the branch and its reinforcement are known.

These can be found for a given vessel and branch by the methods given in **C-3.2.3** and **C-3.3.** Recent experiments in USA, discussed in Reference 16 have shown that slopes and deflections calculated in this way are sufficiently accurate for practical purposes except that the slope of a branch due to a *circumferential* moment is about 75 percent of the calculated value because of the effect of local stiffening by the metal of the branch.

When the loads from the pipework are known, the local stresses in the vessel shell can be found by the methods of **C-3**, except that, in a branch with an external compensating ring of thickness t_1 subject to a *circumferential* moment there is an additional hoop moment in the shell at the edge of the reinforcing ring to N_ϕ ($t_1 - t$)/4 and Reference 17 recommends that this amount should be added to the value of M_ϕ calculated in **C-3.3**.

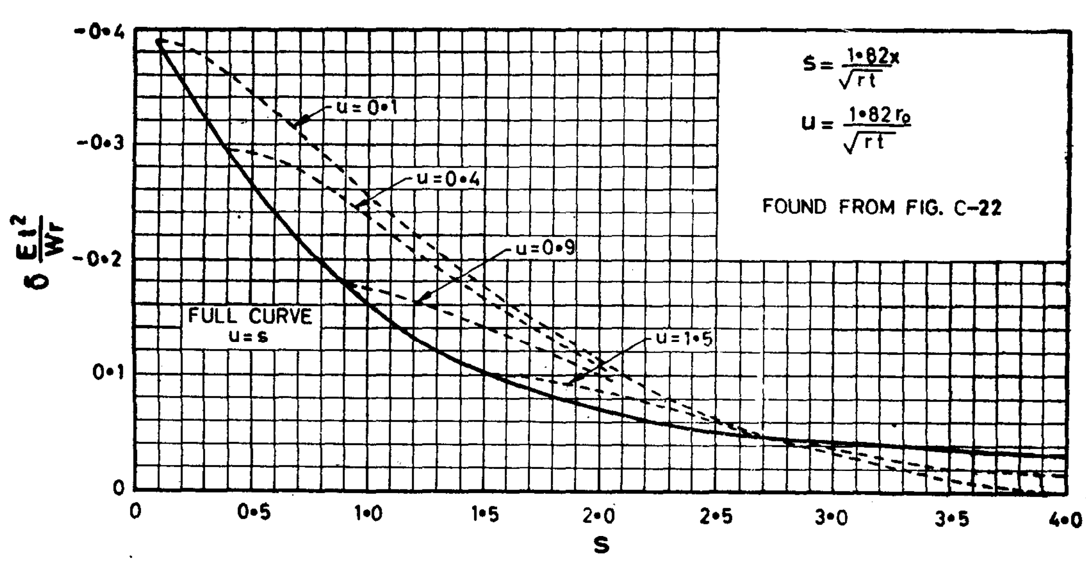


FIG. C.24 DEFLECTIONS OF A SPHERICAL SHELL SUBJECTED TO A RADIAL LOAD *W*

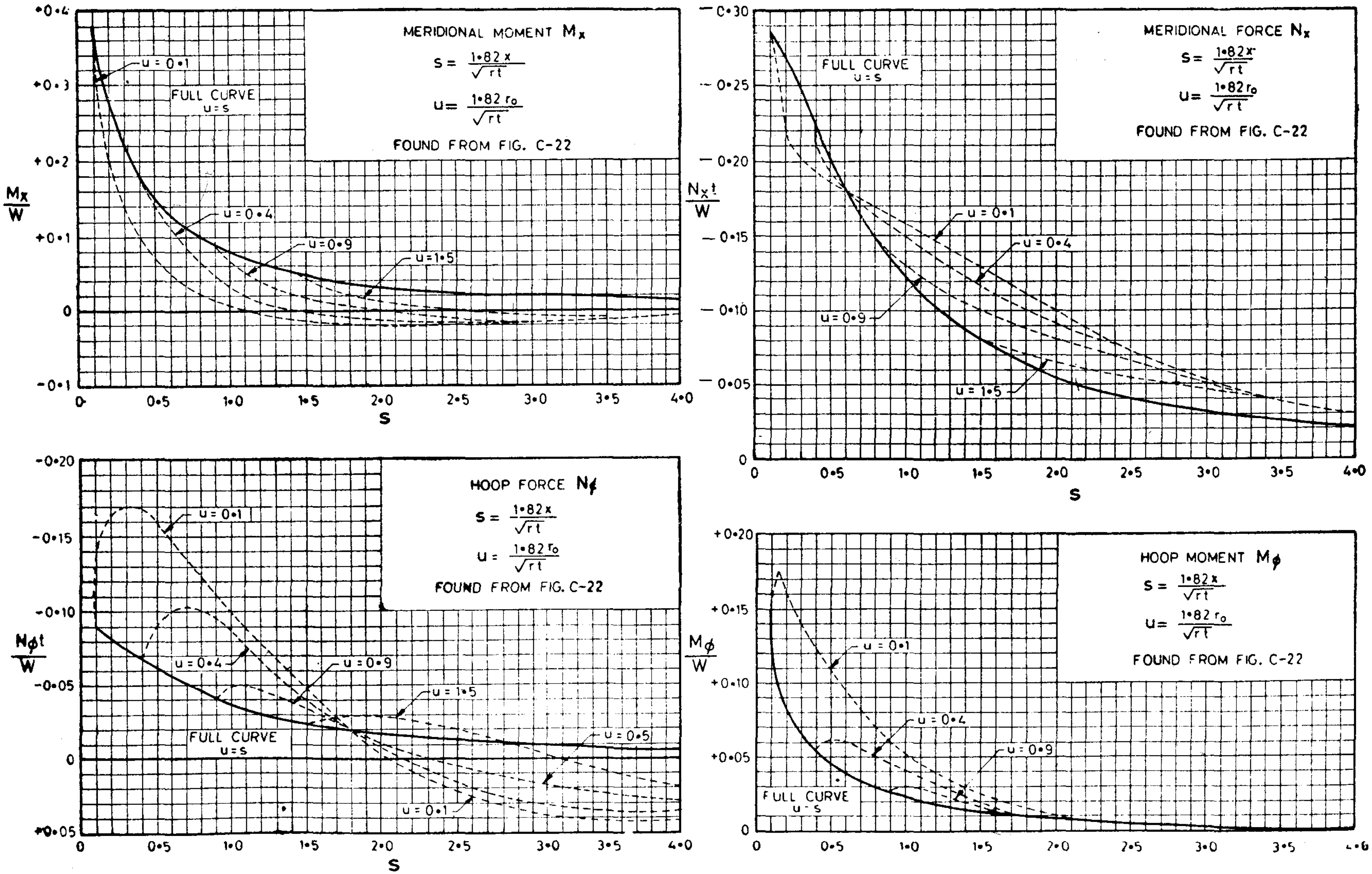


FIG. C.25 MOMENTS AND MEMBRANE FORCES IN A SPHERICAL SHELL SUBJECTED TO A RADIAL LOAD *W*

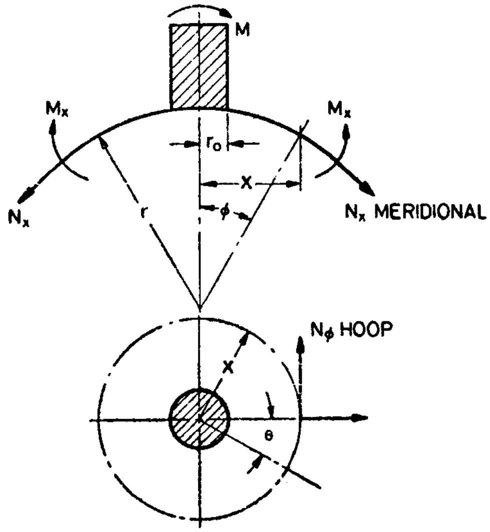


FIG. C.26 EXTERNAL MOMENT APPLIED TO SPHERICAL SHELL

This correction and that to the slope of the branch given above apply only to circumferential moments and are due to the effect of the rigidity of the attachment of the branch which has little influence on the effect of longitudinal moments.

The tension at the inside of the shell due to the local circumferential bending moment M_ϕ is added to the circumferential membrane stress due to internal pressure, but this stress will not be present when the vessel is under hydraulic test.

C-4. SUPPORTS AND MOUNTINGS FOR PRESSURE VESSELS

C-4.1 General Considerations for Supports

C-4.1.1 *Introduction* — This clause and the two which follow are concerned with the supports for pressure vessels and the supports for fittings carried from the shell or ends of the vessel, with regard to their effect on the vessel. The structural design of supports is not included because it can be dealt with by the usual methods. Convenient reference for this is IS : 800-1962*.

The supports of vessels and of fittings carried by the shell produce local moments and membrane forces in the vessel wall which can be treated by the methods given in **C-3**. Notes and cross-references for applying these to various types of support are included.

The supports of a vessel shall be designed to withstand all the external loads likely to be imposed on it in addition to the dead weight of the vessel and contents.

These may include:

a) superimposed loads,
b) wind loads on exposed vessels,
c) thrusts or moments transmitted from connecting pipework,
d) shock loads due to liquid hammer or surging of the vessel contents, and
e) forces due to differential expansion between the vessel and its supports.

*Code of practice for use of structural steel in general building construction (*revised*).

C-4.1.2 *Notation for* **C-4**

Notation	*Unit*	*Description*
a	mm²	Area of effective cross section of a stiffener for a horizontal vessel.
A	mm	Distance from a saddle support to the adjacent end of the cylindrical part.
b	mm	Axial length of a dished end of the vessel.
b_1	mm	Axial width of a saddle support.
c	mm	Distance from centroid of effective area of stiffener to the shell.
$C_1 \dots C_5$	—	Constants.
d	mm	Distance from centroid of effective area of stiffener to tip of stiffener.
E	kgf/mm²	Modulus of elasticity.
f	kgf/mm²	Allowable working stress in tension.
$f_1 \cdots f_3$	kgf/mm²	Resultant stresses in horizontal vessel due to mode of support.
f_n	kgf/mm²	Nominal stress in dished end calculated from **3.5**.
F	kgf	Resultant of horizontal forces acting on a vertical vessel.
H	kgf	Resultant horizontal force in least cross section of a saddle support.
I	mm⁴	Moment of inertia of effective cross section of a stiffening ring.
$K_1 \dots K_{10}$	—	Constants.
L	mm	Length of cylindrical part of vessel.

Notation	*Unit*	*Description*
l	mm	Length of part of shell of a horizontal vessel assumed to act with a ring support.
M_1	kgf·mm	Bending moment in a horizontal ring girder above its own support.
M_2	kgf·mm	Bending moment in a horizontal ring girder midway between its supports.
M_3	kgf·mm	Longitudinal bending moment in a horizontal vessel midway between supports.
M_4	kgf·mm	Longitudinal bending moment in a horizontal vessel at its supports.
p	kgf/cm²	Internal pressure in vessel.
q	kgf/mm²	Shear stress in vessel shell.
q_e	kgf/mm²	Shear stress in vessel end.
r	mm	Radius of cylindrical part of vessel.
r_1	mm	Radius of base of skirt support of vertical vessel.
r_2	mm	Mean radius of horizontal ring girder or of ring support.
t	mm	Thickness of vessel shell.
t_1	mm	Thickness of reinforcing plate.
t_2	mm	Thickness of ring stiffeners.
T	kgf·mm	Maximum twisting moment in a horizontal ring girder.
t_e	mm	Thickness of vessel end.
V	km/h	Wind velocity.
W	kg	Weight of vessel.
W_1	kg	Maximum reaction at a support.
w	kg/m	Average weight of a vertical vessel per metre height.
x	mm	Distance from a support of a horizontal ring girder to the nearest point of maximum twisting moment.
y	mm	Height of the resultant of the horizontal forces acting on a vessel above its supports.
Z	mm³	Section modulus of the effective cross section of a ring support for a horizontal vessel.
θ	degrees	Included angle of a saddle support.
ϕ_1	degrees	Angle between the radius drawn to the position of a support and the vertical centre line of a vessel.

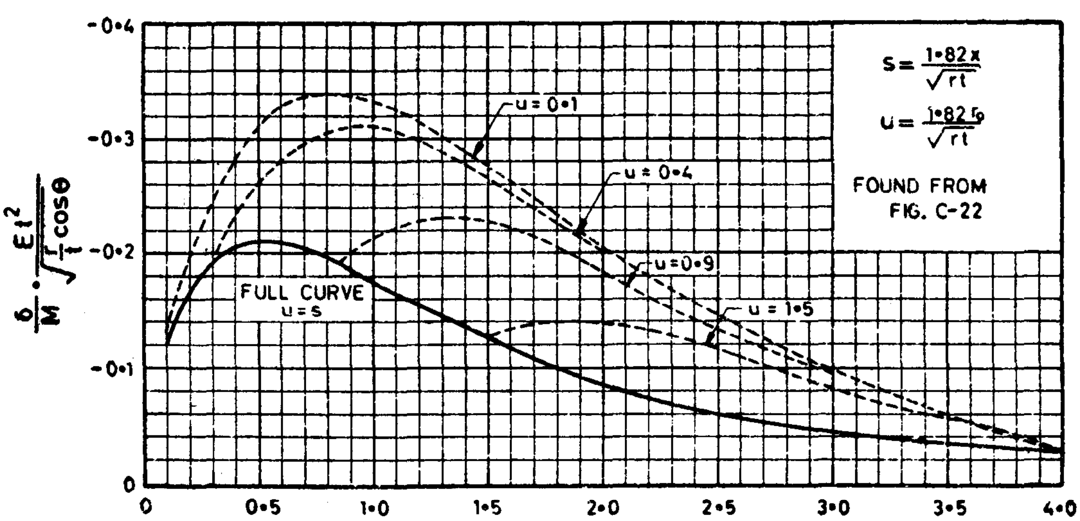


Fig. C.27 Deflections of a Spherical Shell Subjected to an External Moment M

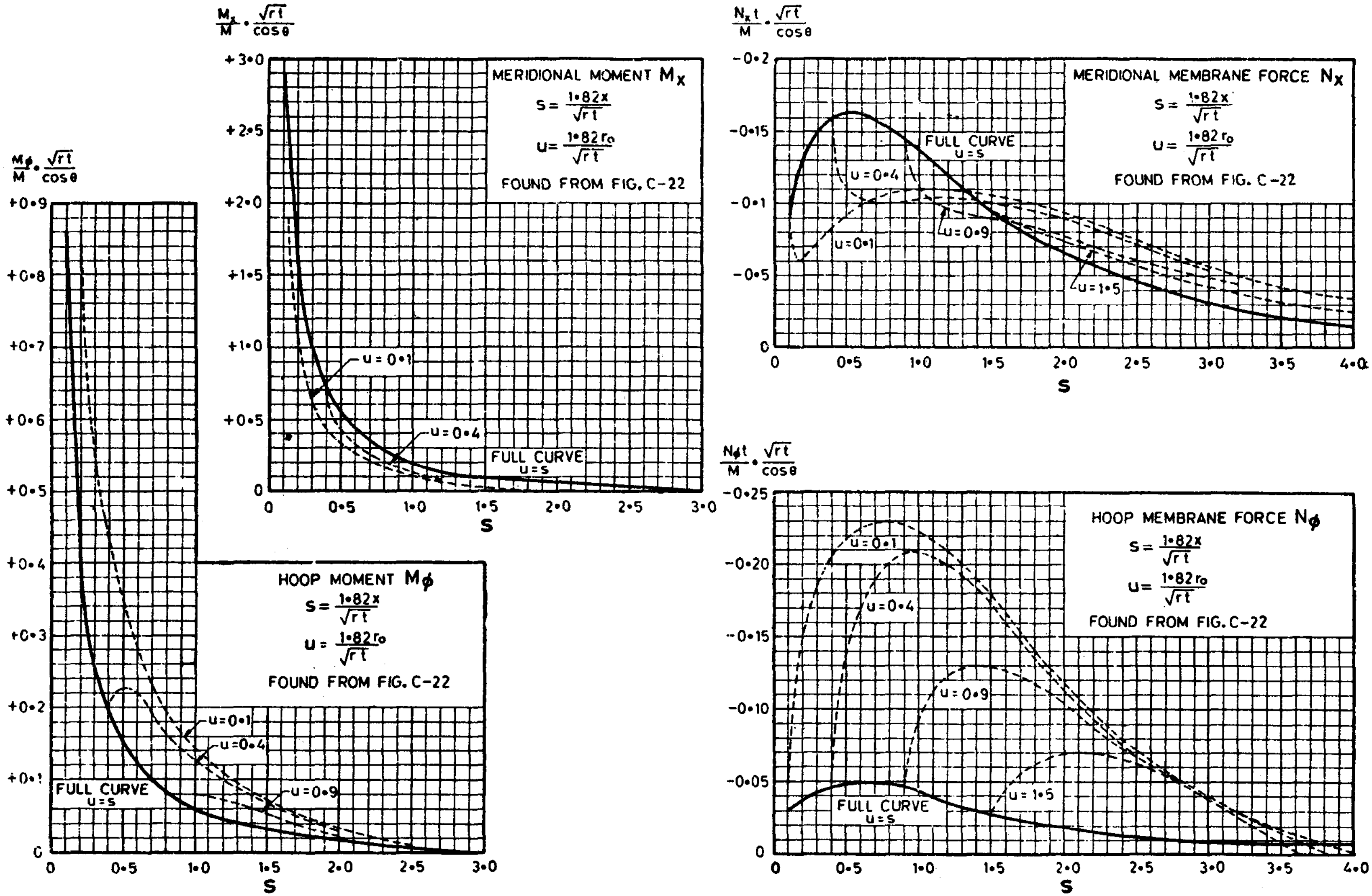


FIG. C.28 MOMENTS AND MEMBRANE FORCES IN A SPHERICAL SHELL SUBJECTED TO AN EXTERNAL MOMENT M

C-4.1.3 *Wind Loads on Exposed Vessels* — The wind pressure to be expected on a tall vessel depends on its site, both geographically and in relation to neighbouring buildings or other obstruction to the wind, and on its total height above ground level.

The values of basic wind pressures at different heights above ground level in the various regions of India have been given in Fig. 1A and accompanying Table of IS : 875-1964*. For the purpose of calculating the external pressures acting on the projected area in the plane perpendicular to the wind, these values will have to be multiplied by a shape factor of 0·7 as recommended in Table 3 of IS : 875-1964*.

The wind pressure found as above is assumed to act over the whole projected area of the vessel. The resultant wind load, required for calculating the reactions at the vessel supports, is assumed to act through the centre of gravity of the projected area.

Vibrations due to wind effects can develop in tall slender vessels without lateral support and having relatively large natural periods of vibration. Such vibrations may lead to fatigue ailure.

Vessels having a natural period of vibration greater than 0·4 to 0·8 seconds, depending on their weight and proportions, may require to be reinforced to avoid this trouble.

Reference 7 gives a design procedure for such cases and methods of finding the natural period of vibration of the vessel.

It is not necessary to apply this procedure to mild steel vessels of uniform diameter, thickness, and contents unless $w.r/t$ exceeds the critical values given in the following table:

L/r	20	30	40	50	60	70	80
$w.r/t$	740 000	104 000	238 00	8 940	3 720	1 490	745

w = weight of vessel in kg per metre height.

L/r = ratio of height of vessel to radius.

Reference 7 also gives methods for finding the natural period of vibration of vessels in which the diameter, thickness or contents is not uniform. The same design procedure can be applied to these.

Vessels having a section packed with ring tiles or coke should be regarded as having non-uniform contents.

C-4.1.4 *Reaction at the Supports* — The reactions at the supports of a vessel can be found by the ordinary methods of statics except in the case of long horizontal vessels supported at more than two positions.

The reactions at the supports of vessels subject to heavy external loads may need to be examined for the following conditions:

a) Working conditions, including full wind load and loads due to pipework.
b) Test conditions, including full wind load, if any, and forces due to the 'cold pull up' of any pipes which will remain connected to the vessel during tests.
c) Shut down conditions, vessel empty and exposed to full wind load, if any, and the forces due to 'cold pull up' in the pipe system connected to it.

Anchor bolts shall be provided if there is an upward reaction to any support under any of these conditions.

The theoretical reactions at the supports of long horizontal vessels supported at more than two positions can be found by the methods used for continuous beams but the calculated values are always doubtful because of settlement of the supports and initial errors of roundness or straightness in the vessel.

C-4.1.5 *Brackets* — Brackets are fitted to the shells of pressure vessels either to support the vessel or some structure which has to be carried from it. Typical brackets are shown in Fig. C.29.

The brackets themselves are designed by the ordinary methods used for brackets supporting beams in structural engineering.

A bracket always applies an external moment to the shell = $W_1.a$.

The effect of this moment on the shell can be found by the method given in **C-3.3**. If the local stresses found in this way are excessive, a reinforcing plate, designed as in **C-4.1.6**, should be fitted between the bracket and the vessel wall.

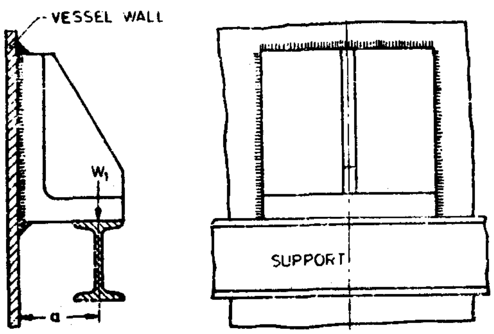
In addition to the vertical loads, the brackets supporting a vertical vessel may be subject to tangential forces due to thrusts and moments transmitted from pipework. Such brackets impose a circumferential moment on the vessel wall in addition to the longitudinal moment. The stresses due to this can be calculated and added to the others but ring or skirt supports are preferable in cases of this type.

C-4.1.6 *Reinforcing Plates* — Reinforcing plates are required when the local stresses in the vessel shell found as in **C-3** for the connection of a support or mounting is excessive. Figure C.30 shows a typical reinforcing plate applied to a cylinder.

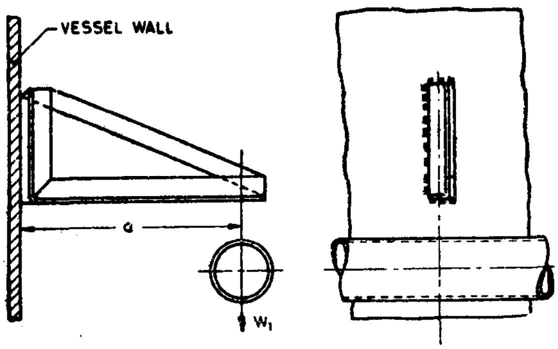
The stresses in the vessel wall at the edge of the reinforcing plate are approximately equal to those calculated by assuming the load or moment to be distributed over the whole area of the reinforcing plate $2d_x \times 2d_\phi$ and proceeding as in **C-3.2.2** for a radial load or in **C-3.3** for a moment.

A safe approximation for the maximum stresses in the reinforcing plate, which occur at the edges

*Code of practice for structural safety of buildings: Loading standards (*revised*).



BRACKET FOR VESSEL SUPPORT



BRACKET FOR EXTERNAL LOAD

FIG. C.29 TYPICAL BRACKETS

of the actual loaded area $2C_x \times 2C_\phi$, is given by the following procedure:

a) Find the maximum moment M_ϕ and M_x and the maximum membrane forces N_ϕ and N_x for the same loading applied to a cylinder of thickness $(t+t_1)$ from the charts of **C-3.2.2** for a radial load or from **C-3.3** and **C-3.2.3** for a moment.

b) Find the resultant stresses due to these by assuming that the vessel wall and the reinforcing plate share the moments M_ϕ and M_x in proportion to the squares of their thicknesses and the membrane forces N_ϕ and N_x in direct proportion to their thicknesses.

Reinforcing plates for spherical vessels and the spherical parts of vessel ends can be designed by applying the charts of **C-3.4.2** and **C-3.4.3** in the same way.

The deflection at a support or fitting provided with a reinforcing plate is approximately equal to the sum of the deflections of the wall of a cylinder or sphere of thickness $(t+t_1)$ loaded over the actual loaded area, and of the wall of a cylinder or sphere of thickness t loaded over the area of the reinforcing plate. These are found from **C-3.2.3** for cylinders or **C-3.4.2** and **C-3.4.3** for spheres and spherical parts of vessel ends.

The slope due to an external moment can be found from the deflection calculated as above by the method given in **C-3.3** and **C-3.4**.

Recent experimental work, discussed in Reference 17 has shown that there is some stress concentration near the sharp corners of rectangular reinforcing plates. Rounded corners are, therefore, preferable.

C-4.2 Supports for Vertical Vessels — This clause is concerned with the design of supports for vertical vessels except where the conventional methods of simple applied mechanics can be used directly.

The design of brackets used to connect the vessel to its supports is given in **C-4.1.5**.

C-4.2.1 *Skirt Supports* — Skirt supports, as shown in Fig. C.31, are recommended for large vertical vessels because they do not lead to concentrated

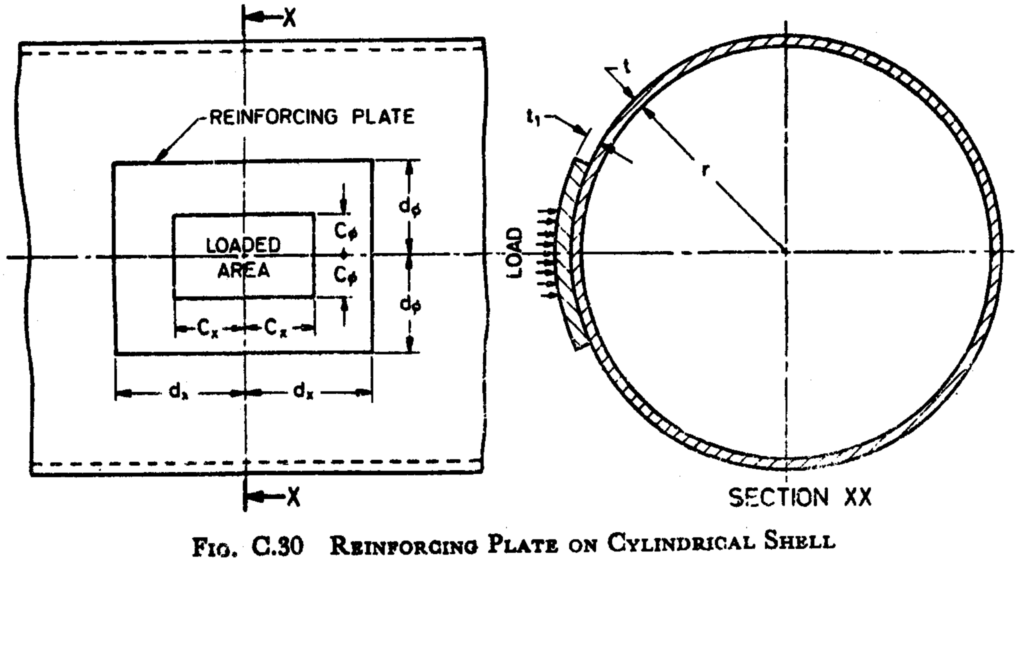


FIG. C.30 REINFORCING PLATE ON CYLINDRICAL SHELL

local loads on the shell, offer less constraint against differential expansion between the part of the vessel under pressure and its supports, and reduce the effect of discontinuity stresses at the junction of the cylindrical shell and the bottom. Skirt supports should have at least one inspection opening to permit examination of the bottom of the vessel unless this is accessible from below through supporting framing. Such openings may need to be compensated.

In general cylindrical skirt supports should be designed in accordance with **3.13** but the critical stresses for buckling should be checked by the methods of **C-5.2** for large or heavily loaded skirt supports. The critical load for a conical skirt support may be found as in **C-5.3.1**.

Skirt supports may also be applied to spherical vessels and to the spherical parts of vessel ends. The local stresses due to skirt supports in these positions should be calculated as in **C-3.4**.

C-4.2.1.1 *Overturning moments on skirt supports* — At any horizontal section of a skirt support, the maximum load per linear millimetre of the skirt circumference is given by:

$$N_x = \frac{W}{2\pi r} \pm \frac{F\bar{Y}}{\pi r^2} = \text{stress} \times \text{thickness of skirt.}$$

If there is negative value of N_x, anchor bolts will be necessary because there will be a net moment of $M = Wr_1 - F\bar{Y}$ tending to overturn the vessel about the leeward edge of the skirt support flange.

For small vessels the anchor bolts can be desinged on the assumption that the neutral axis of the bolt group lies along a diameter of the support flange, but this assumption leads to overdesign in the case of tall vessels with large overturning moments because the effect of the elasticity of the foundation, which produces an additional resisting moment, is neglected.

Reference 16 gives suitable design procedures for such cases.

C-4.2.1.2 *Discontinuity stresses at skirt supports* — The presence of a skirt support reduces the discontinuity stresses at the junction of the bottom and the vessel wall.

Reference 18 gives a procedure for calculating the actual discontinuity stresses and also the design of skirt supports for vessels subject to severe cyclic loading due to thermal stresses.

C-4.2.2 *Ring Supports for Vertical Vessels* — It is often convenient to support vertical vessels from steelwork by means of a ring support in a convenient position on the shell as shown in Fig. C.32.

Such a ring support corresponds to one flange of a bolted joint with the 'hub' of the flange extending on both sides and with the couple due to the bolts replaced by that due to the eccentricity between the supporting force and the vessel wall.

All ring supports of this type should rest on some form of continuous support or on steelwork as indicated in Fig. C.33. They should not be used to connect vessels directly to leg or column supports, but should rest on a ring girder or other steelwork joining the tops of the columns.

C-4.2.3 *Leg Supports for Vertical Vessels* — Leg supports for vertical vessels can, in general, be designed by the usual methods of applied mechanics, for example, those described in Reference 6 (*see* **C-6**).

They should always be arranged as close to the shell as the necessary clearance for insulation will permit.

If brackets are used to connect the legs to the vertical wall of the vessel as in Fig. C.34A they should be designed as described in **C-4.1.5** and fitted with reinforcing plates if required.

Short legs, or legs braced together to resist horizontal forces may impose a severe constraint on a vessel wall due to differences in thermal expansion. This constraint can be avoided by using brackets on the vessel wall provided with slotted holes to allow for expansion.

It is sometimes convenient to support small vessels not subject to large horizontal forces by legs connected to the curved surface of the bottom as shown in Fig. C.34B.

The connections of such supports should be designed to withstand a radial load of $W_1/\cos \phi_1$, where W_1 is the greatest reaction at the support. The local stresses due to this load should be found from the charts of **C-3.4** and a reinforcing plate designed as in **C-4.1.6** fitted if necessary.

C-4.2.4 *Ring Girders* — The supporting legs of large vertical vessels and spherical vessels are often connected to a ring girder which supports the vessel shell. In some designs the lower part of a skirt support is reinforced to form a ring girder. Figure C.35 shows a typical ring girder.

Such girders are subject to torsion as well as bending and require special consideration.

When the supporting columns are equally spaced, the bending and twisting moments in the ring girder can be found from the following table, taken from Reference 20:

No. of legs	4	6	8	12
Load on each leg	$W/4$	$W/6$	$W/8$	$W/12$
Max shear in ring girder	$W/8$	$W/12$	$W/16$	$W/24$
M_1/Wr_2	−0·034 2	−0·014 8	−0·008 27	−0·003 65
M_2/Wr_2	+0·017 6	+0·007 51	+0·004 15	+0·001 90
x/r_2	0·335	0·222	0·166	0·111
T/Wr_2	0·005 3	0·001 5	0·000 63	0·000 185

where

M_1 = the bending moment in the girder above a support,

M_2 = the bending moment in the girder midway between supports,

r_2 = mean radius of girder,

T = the maximum twisting moment in the girder and,

x = distance from a support to the point of maximum torsion measured round the mean circumference.

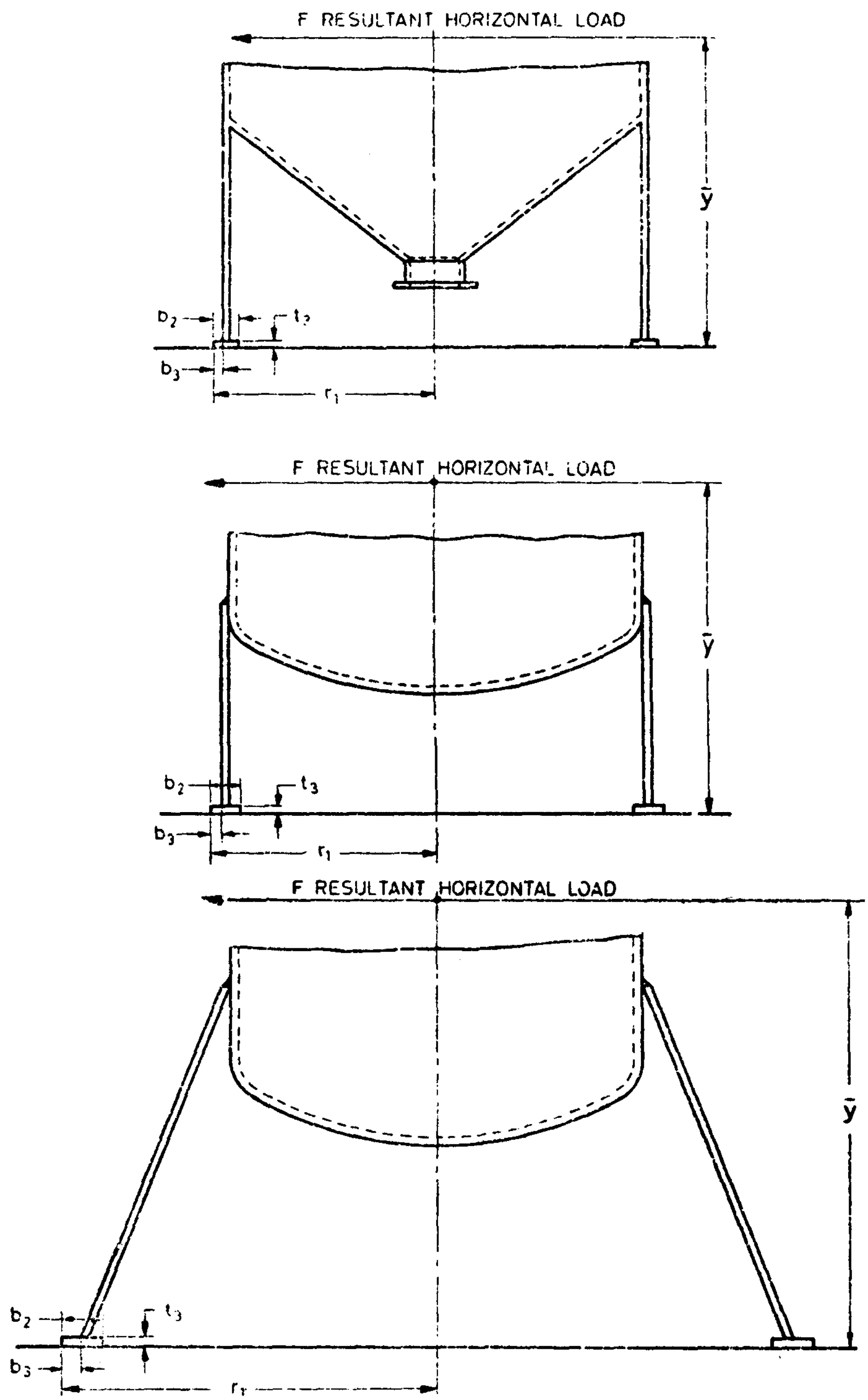


FIG. C.31 TYPICAL SKIRT SUPPORT

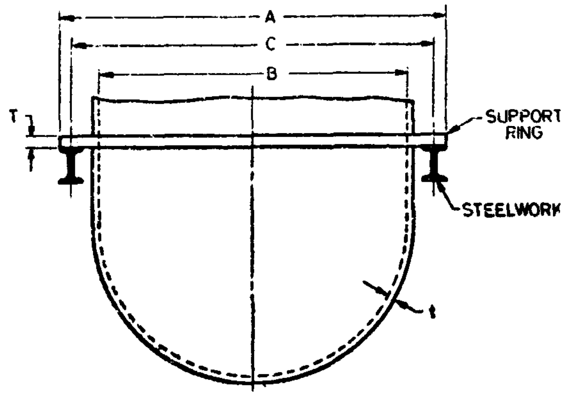


Fig. C.32 Typical Ring Support

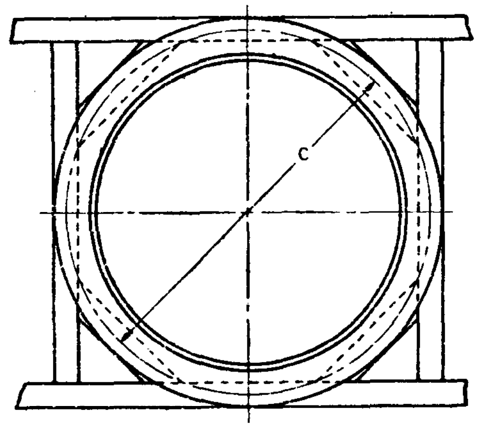
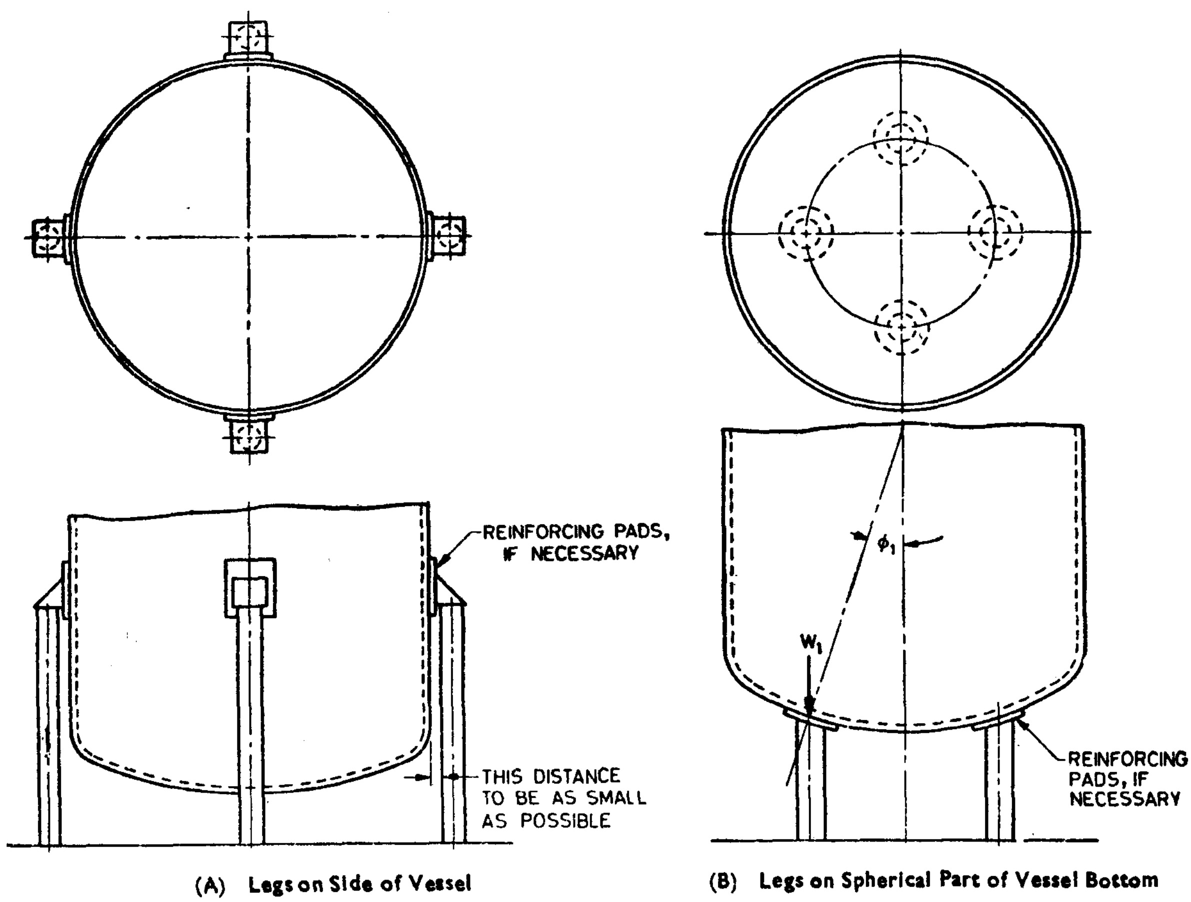


Fig. C.33 Typical Steelwork Under Ring Support



(A) Legs on Side of Vessel

(B) Legs on Spherical Part of Vessel Bottom

Fig. C.34 Leg Supports for Vertical Vessels

Any consistent system of units can be used for these quantities.

A bending moment causing tension at the underside of the girder is taken as positive.

The torsion in the girder is zero at the supports and midway between them and the bending moment is zero at the points of maximum torsion.

C-4.3 Supports and Mountings for Horizontal Vessels

C-4.3.1 *General Considerations* — Horizontal vessels are subject to longitudinal bending moments and local shear forces due to the weight of their contents.

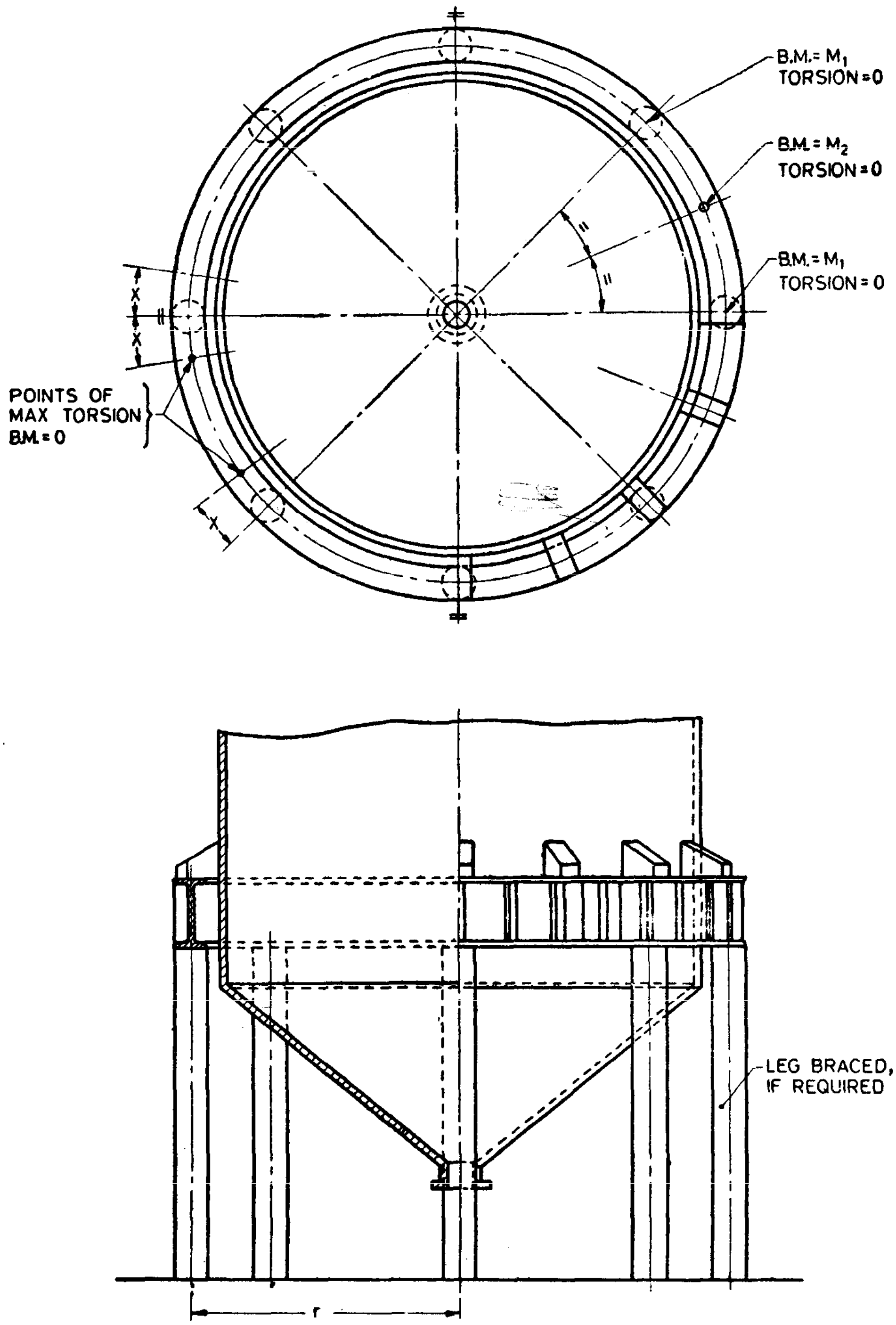


FIG. C.35 TYPICAL RING GIRDER

They are conveniently supported on saddles (Fig. C.36A), rings (Fig. C.36B), or leg supports (Fig. C.36C).

Horizontal vessels should be supported at two cross sections only whenever possible. If they are supported at more than two cross sections the distribution of the reactions is affected by small variations in the level of the supports, the straightness and local roundness of the vessel shell and the relative stiffness of different parts of the vessel against local deflections. It is often preferable to stiffen a vessel so that it may be supported at two points only rather than to increase the number of supports. Ring supports are preferable to saddle supports for vessels in which support at more than two cross sections is unavoidable.

The supports of vessels which are to contain gases or liquids lighter than water should be

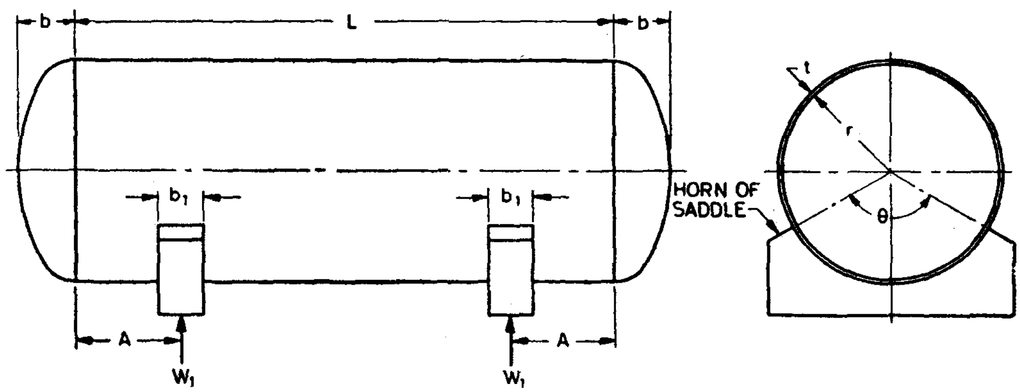
designed to support the vessel when full of water because of the need for periodical hydraulic tests.

The use of leg supports should be confined to small vessels in which the longitudinal bending stresses are small compared to the axial stress due to the working pressure and the local stresses due to the reactions at the supports, found as in **C-3**, can be kept within acceptable limits.

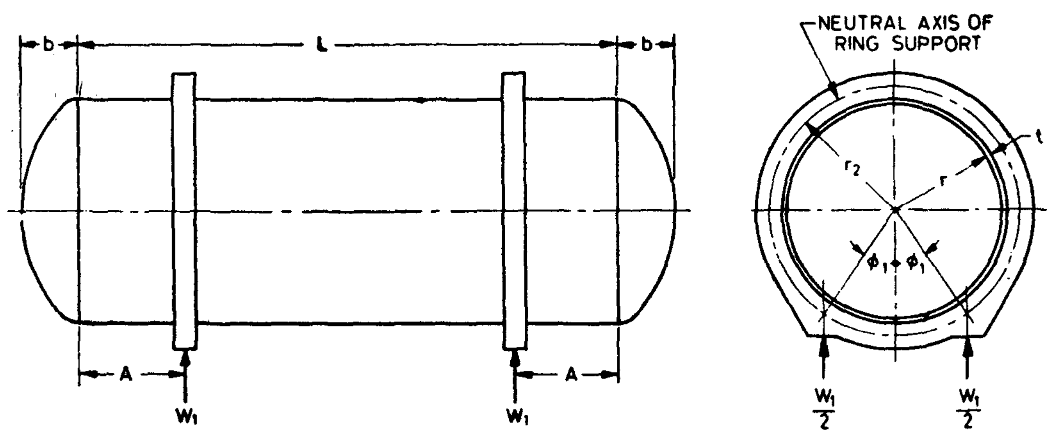
Ring supports are preferable to saddle supports for large thin walled vessels and for vacuum vessels.

The mountings and brackets which carry loads supported from the vessel shell should be designed as described for vertical vessels in **C-4.1**.

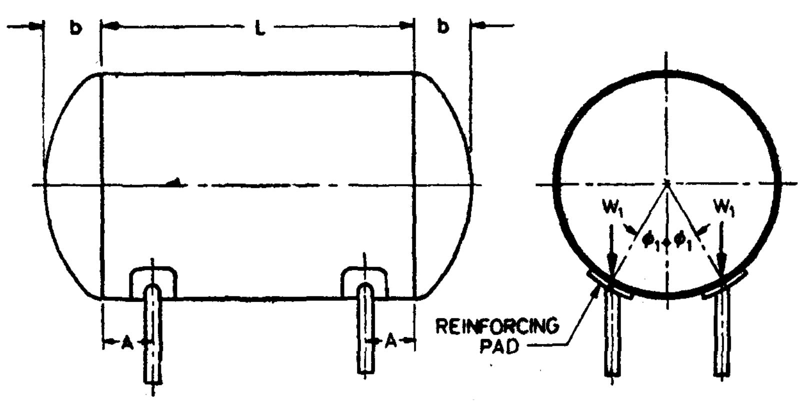
It may be necessary to provide ring supports for heavy fittings or structures supported from the vessel.



(A) SADDLE SUPPORTS



(B) RING SUPPORTS



(C) LEG SUPPORTS FOR SMALL VESSELS

Fig. C.36 Typical Supports for Horizontal Vessels

C-4.3.2 *Saddle Supports* — Saddle supports, as shown in Fig. C.36A are the most frequently used type of support for horizontal vessels although no rigorous analytical treatment of them is available. The methods given in **C-3** are not strictly applicable to loaded areas extending over the large proportion of the total circumference of the vessel which is usual for saddle supports. The following treatment which is based on an approximate analysis discussed in Reference 19. The analysis gives a good approximation to the results of strain gauge tests on large vessels (Reference 19).

The included angle of a saddle support, θ in Fig. C.36A, should not normally be less than 120°. This limitation, which is imposed by most codes of practice, is an empirical one based on experience of large vessels.

NOTE — The work of Zick (Reference 19) applies to normal thickness/diameter ratios and errors can occur if the method is extrapolated to apply to large thickness/diameter ratios. In such cases, or in cases where doubt arises, the method to be employed in computing stresses due to support loads shall be agreed between the purchaser and the manufacturer.

C-4.3.2.1 *Longitudinal bending moments and stresses in the vessel shell* — Figure C.37 shows the loads, reactions, and longitudinal bending moments in a vessel resting on two symmetrically placed saddle supports. The bending moments are given by the following equations:

at mid-span $M_3 =$

$$\frac{W_1 L}{4}\left\{\frac{1+\dfrac{2(r^2-b^2)}{L^2}}{1+\dfrac{4b}{3L}}-\frac{4A}{L}\right\} \quad \dots \quad (C.6)$$

at supports $M_4 =$

$$-W_1 A\left\{1-\frac{1-\dfrac{A}{L}+\dfrac{(r^2-b^2)}{2AL}}{1+\dfrac{4b}{3L}}\right\} \dots (C.7)$$

A positive bending moment found from these expressions is one causing tension at the lowest point of the shell cross section. The moment M_4 may be positive in vessels of large diameter with supports near the ends because of the effect of hydrostatic pressure (*see* Fig. C.37).

When $\dfrac{L}{r}$ and $\dfrac{b}{r}$ are known, these reduce to

$$M_3 = W_1 (C_1 L - A)$$

where C_1 is a factor obtained from Fig. C.38 and

$$M_4 = \frac{W_1 A}{C_2}\left[1-\frac{A}{L}+C_3\frac{r}{A}-C_2\right]$$

where C_2 and C_3 are factors obtained from Fig. C.39.

Similar expressions for the longitudinal bending moments can be obtained by the ordinary methods of statics, for example, References 1, 8, 9, 10, 11 and 12, for vessels in which the supports are not symmetrically placed, if W (the total weight of the vessel) is substituted for $2W_1$ in the expressions for the loads shown in Fig. C.37.

The above expressions for the longitudinal bending moments can be applied to horizontal vessels with other types of support.

C-4.3.2.2 *Longitudinal bending stresses at mid-span* — The resultant longitudinal stresses at mid-span due to pressure and bending are given by the following expressions:

At the highest point of the cross section,

$$f_1 = \frac{pr}{2t \times 100} - \frac{M_3}{\pi r^2 t} \quad \dots \quad (C.8)$$

At the lowest, $f_2 = \dfrac{pr}{2t \times 100} + \dfrac{M_3}{\pi r^2 t} \quad \dots \quad (C.9)$

C-4.3.2.3 *Longitudinal bending stresses at the saddles* — These depend on the local stiffness of the shell in the plane of the supports, because, if the shell does not remain round under load, a portion of the upper part of its cross section, as shown in Fig. C.40 is ineffective against longitudinal bending.

When the supports are near the end of the vessel, so that $A < r/2$, the stiffness of the ends is enough to maintain a circular cross section. Such shells are said to be stiffened by the ends.

The resultant longitudinal stresses due to pressure and bending are given by:

a) at the highest point of the cross section in shells which remain round in the plane of the support or near the horizontal mid-plane in those which do not,

$$f_3 = \frac{pr}{2t \times 100} - \frac{M_4}{K_1 \pi r^2 t} \quad \dots \quad (C.10)$$

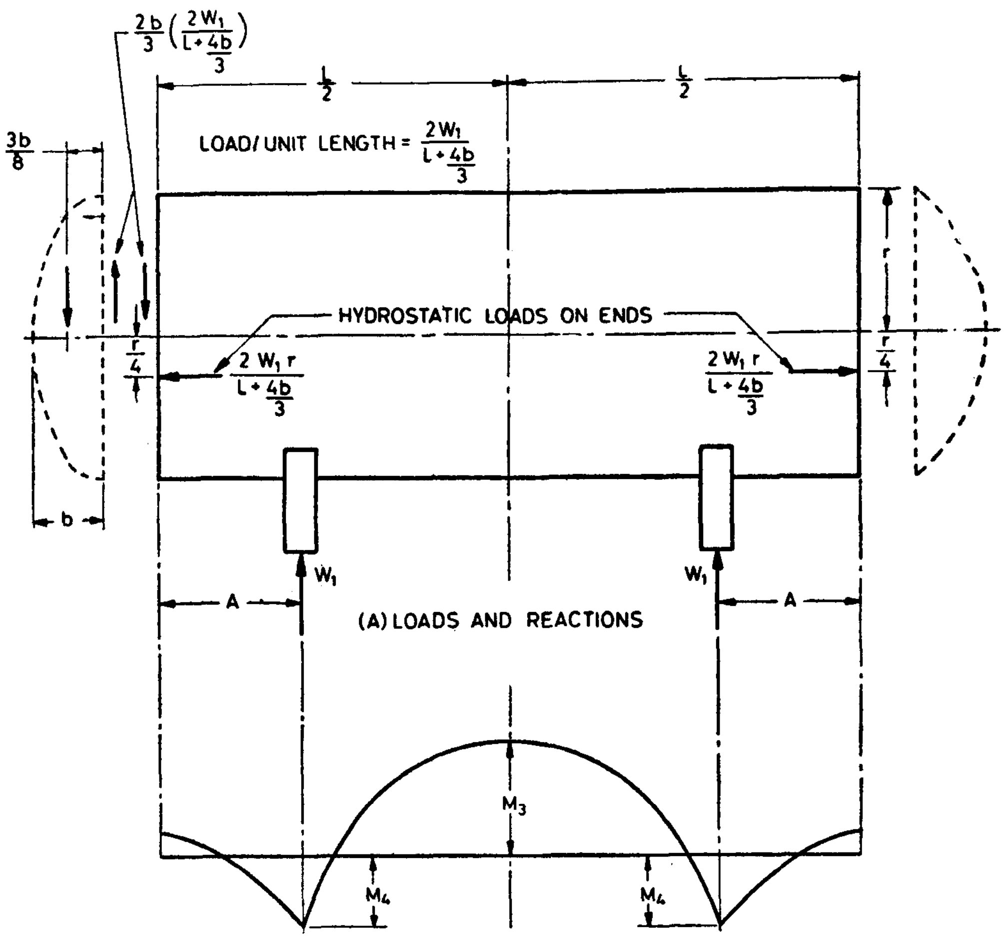
b) At the lowest point of the cross section,

$$f_4 = \frac{pr}{2t \times 100} + \frac{M_4}{K_2 \pi r^2 t} \quad \dots \quad (C.11)$$

Values of K_1 and K_2 are given in Table C.4.

TABLE C.4 VALUES OF FACTORS K_1 AND K_2

Condition	Saddle Angle θ (Degrees)	K_1	K_2
Shell stiffened by end or rings	120	1	1
That is, $A < r/2$ or rings provided	150	1	1
Shell unstiffened by end or rings	120	0·107	0·192
That is, $A > r/2$ and no rings provided	150	0·161	0·279



Positive values of M_4 are obtained for the following forms and proportions:

Flat ends	$\frac{A}{r} < 0{\cdot}707$
Ends with 10 percent knuckle radius	$\frac{A}{r} < 0{\cdot}44$
Semi-ellipsoidal ends 2 : 1 ratio	$\frac{A}{r} < 0{\cdot}363$

M_4 is always negative for hemispherical ends.

(B) Moment Diagram

FIG. C.37 CYLINDRICAL SHELL ACTING AS BEAM OVER SUPPORTS

Tensile stresses should not exceed the allowable design stress.

Compressive stresses should not numerically exceed the allowable design stress or $\frac{Et}{16r}$ whichever is the less.

C-4.3.2.4 *Tangential shearing stresses* — The load is transferred from the unsupported part of the shell to the part over the supports by tangential shearing stresses which vary with the local stiffness of the shell.

Case 1. Shell not stiffened by vessel end

$$\left(A > \frac{r}{2} \right)$$

The maximum tangential shearing stress is given by:

$$q = \frac{K_3 W_1}{rt} \left(\frac{L - 2A - b}{L + b} \right) \quad \ldots \quad (\text{C.12})$$

This expression does not apply when $A > L/4$ but such proportions are unusual.

The value of K_3 depends on the presence or absence of supporting rings and on the saddle angle θ. It is given in Table C.5.

The thickness of local doubling plates shall not be included when using equation (C.12).

Case 2. Shell stiffened by end of vessel

$$\left(A < \frac{r}{2} \right)$$

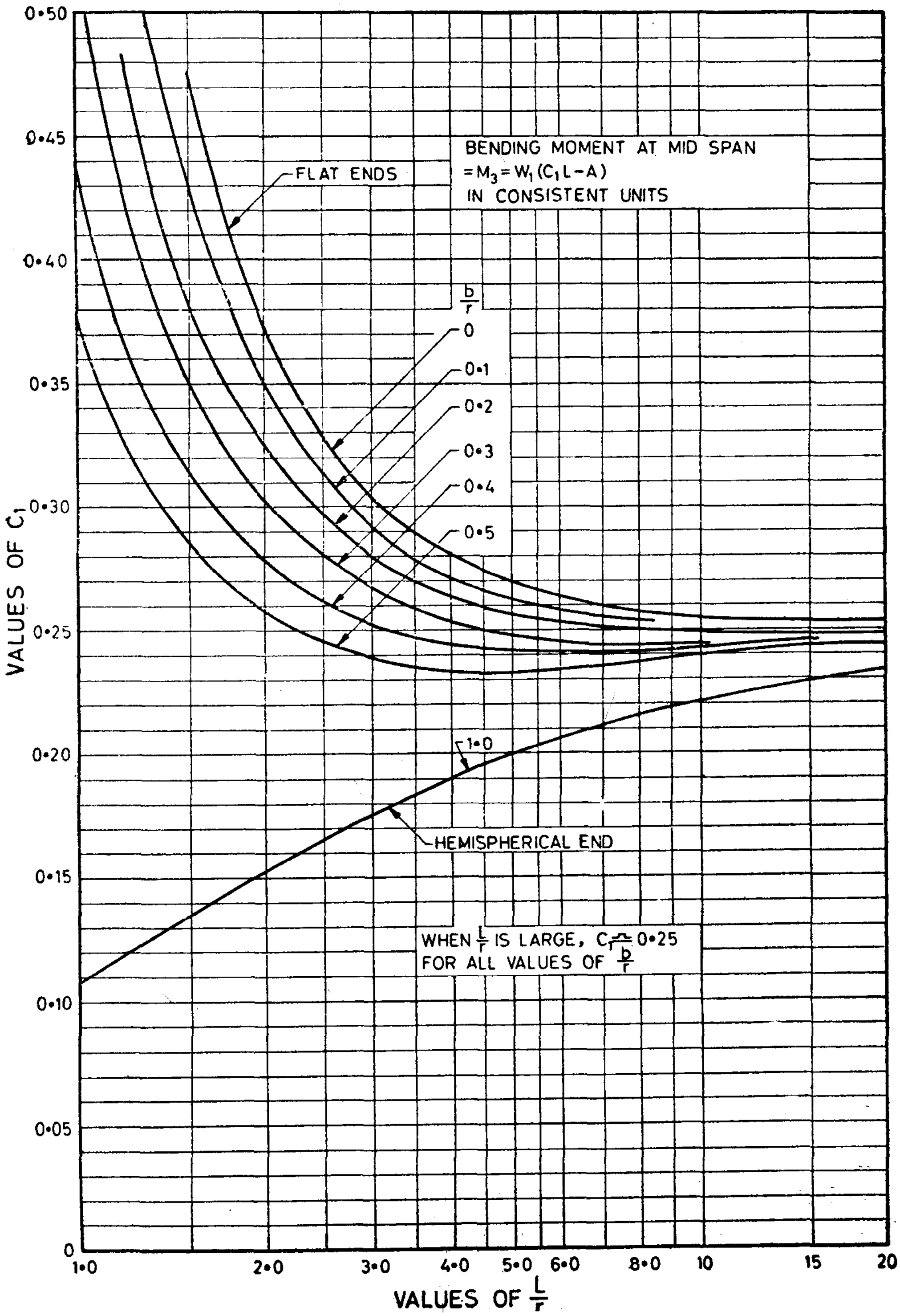


FIG. C.38 FACTOR FOR BENDING MOMENT AT MID-SPAN

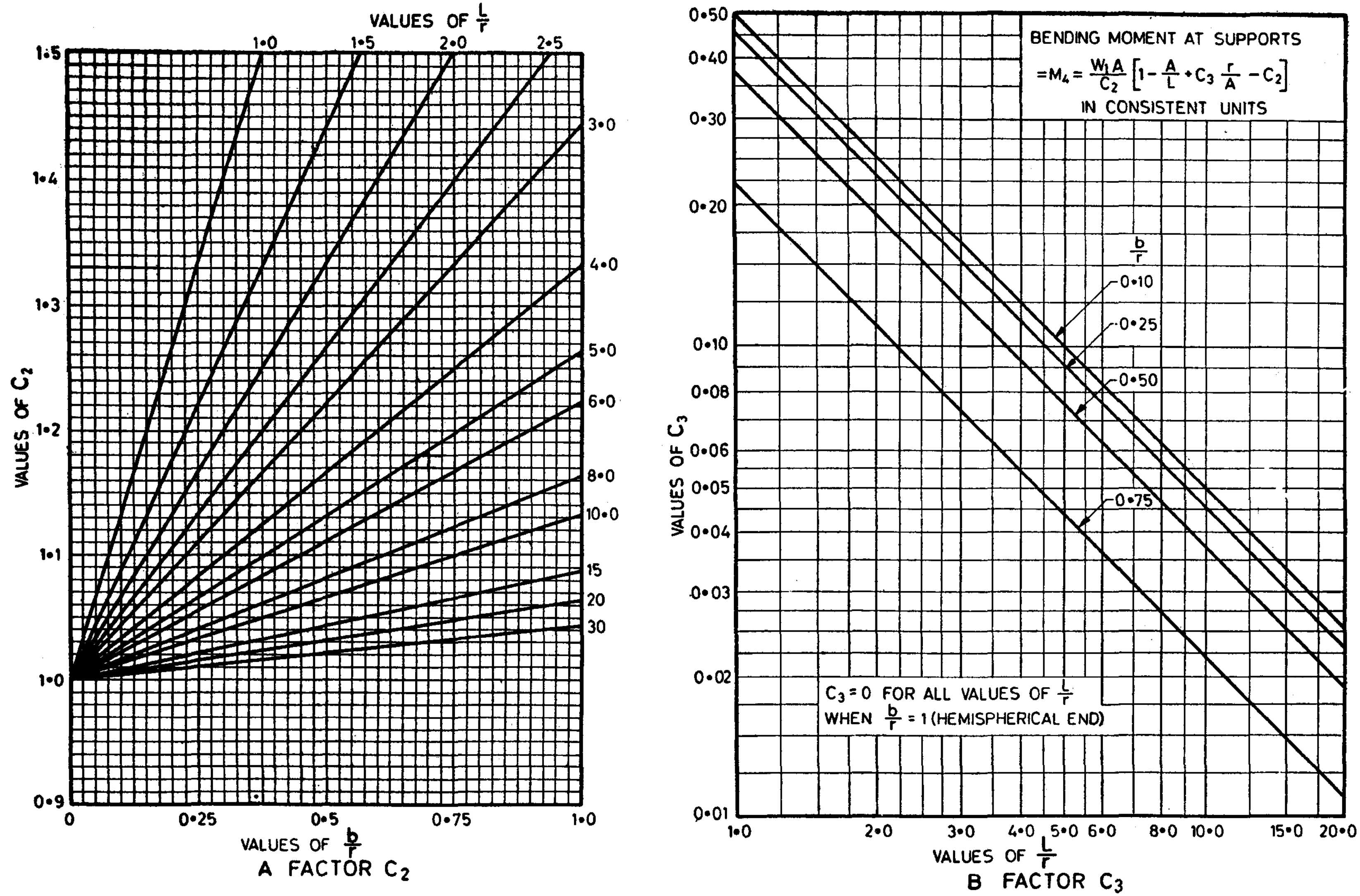


FIG. C.39 FACTORS FOR BENDING MOMENT AT SUPPORTS

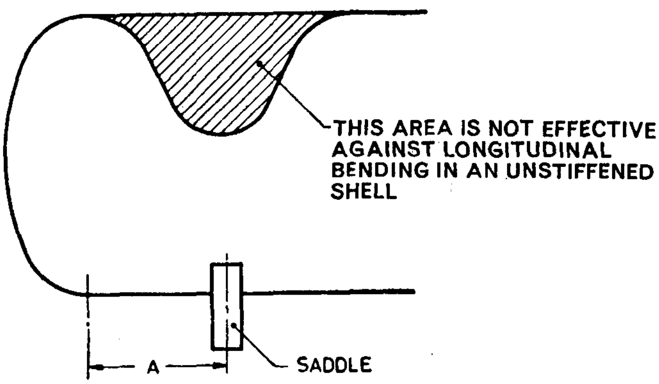


FIG. C.40 PORTION OF SHELL INEFFECTIVE AGAINST LONGITUDINAL BENDING

In this case there are shearing stresses in both the shell and the vessel end, given by:

$$q = \frac{K_3 W_1}{rt} \text{ in the shell} \quad \ldots \quad (\text{C.13})$$

$$q_e = \frac{K_4 W_1}{rt_e} \text{ in the end} \quad \ldots \quad (\text{C.14})$$

The values of K_3 and K_4 depend on the width b_1 of the saddle (Fig. C.36A) and on the saddle angle θ. They are given in Table C.5.

TABLE C.5 VALUES OF FACTOR K_3 AND K_4

(*Clause* C-4.3.2.4)

Condition		Saddle Angle (Degrees)	K_3	K_4
$A > r/2$ and shell unstiffened by rings		120 150	1·171 0·799	— —
$A > r/2$ and shell stiffened by rings in plane of saddles		120 150	0·319 0·319	— —
$A > r/2$ and shell stiffened by rings adjacent to saddles		120 150	1·171 0·799	— —
Shell stiffened by end of vessel	$b_1 < A \leqslant r/2$	120 150	0·880 0·485	0·401 0·297
	$\frac{b}{2} < A < b$	120 150	0·880 0·485	0·880 0·485

It has been suggested (Reference 19), that the maximum allowable values of the tangential stresses should be:

$q = 0{\cdot}8f$ in the shell

and $q_e = (1{\cdot}15f - f_n)$ in the end

where $f_n = p{\cdot}D_0K/2t \times 100$ in which K is the shape factor from Fig. 3.7.

These high values can be allowed because the resultant combined stresses are local in character and will be relieved in practice by prestressing due to local yielding.

The suggested values are empirical and were derived from strain gauge tests on large vessels.

C-4.3.2.5 *Circumferential stresses* — Figure C.41 shows the circumferential bending moments diagrammatically. There is no rigorous analysis of these moments and the constants in the following stress formulae were determined experimentally (Reference 19).

The circumferential stresses should be evaluated at the following two positions around the circumference for each vessel investigated:

a) At the lowest point of the cross section. The stress at this position will be denoted by f_5.

b) 1) At the horn of the saddle (where $\beta = 180 - \frac{\theta}{2}$ in Fig. C.41) when the shell is unstiffened by means of rings.

   This stress is denoted by f_6.

   2) At the horn of the saddle (Fig. C.36A) when the shell is stiffened with rings in the plane of the saddle.

   3) At the equator ($\alpha = 90°$) when the shell is stiffened with rings adjacent to the saddle.

When the shell is stiffened with rings, the stresses in the rings will be denoted by f_7 and f_8. Both of these stresses shall be investigated.

C-4.3.2.6 *For a shell not stiffened by rings* — At the lowest point of the cross section:

$$f_5 = \frac{-K_5 W_1}{t(b_1 + 10t)} \quad \ldots \quad \ldots \quad (\text{C.15})$$

The stress f_6 at the horn of the saddle depends on the ratio of length to radius of the vessel.

$$\text{If } \frac{L}{r} > 8,\ f_6 = \frac{-W_1}{4t(b_1 + 10t)} - \frac{3K_6W_1}{2t^2} \qquad \dots \dots (C.16)$$

$$\text{If } \frac{L}{r} < 8,\ f_6 = \frac{-W_1}{4t(b_1 + 10t)} - \frac{12K_6W_1 r}{Lt^2} \qquad \dots \dots (C.17)$$

Values of K_5 are given in Table C.6 as for 'rings adjacent to saddle' and K_6 is found from Fig. C.42.

These stresses may be reduced if necessary by welding a reinforcing plate to the shell between it and the saddle as shown in Fig. C.43.

If the width of this plate is not less than $(b_1 + 10t)$ and it subtends an angle not less than $(\theta + 12)$ degrees at the horizontal centre line of the cylinder, the reduced stresses at the edge of the saddle can be obtained by substituting $(t + t_1)$, the combined thickness of shell and reinforcing plate, for t in the above equations.

The stresses in the shell at the edge of the reinforcing plate should be checked by equations (C.15), (C.16) and (C.17), taking the saddle to have the dimensions and included angle of the reinforcing plate. Values of K_6 can be interpolated from Fig. C.42, taking $K_6 = 0$ when $\theta = 180°$. If these are unacceptable both the width and included angle of the reinforcing plate should be increased from the minimum values specified above.

C-4.3.2.7 *For a shell stiffened by rings*

The shell may be stiffened by means of:

a) a ring welded to the inside of the shell in the plane of each saddle, as shown in Fig. C.44A, and

b) two rings adjacent to each saddle, welded either to the inside or outside of the shell, as shown in Fig. C.44B and C.44C. Reference 19 suggests that the axial length of shell between the stiffeners should be not less than 10 times the shell thickness and not more than the mean radius of the shell.

The stiffeners shown in the figures are of rectangular section. Stiffeners of other sections may be used if preferred.

The expressions for the stresses are given below:

$$f_5 = \frac{-K_5W_1}{t(b_1 + 10t)} \text{ at the lowest point of cross section} \dots (C.18)$$

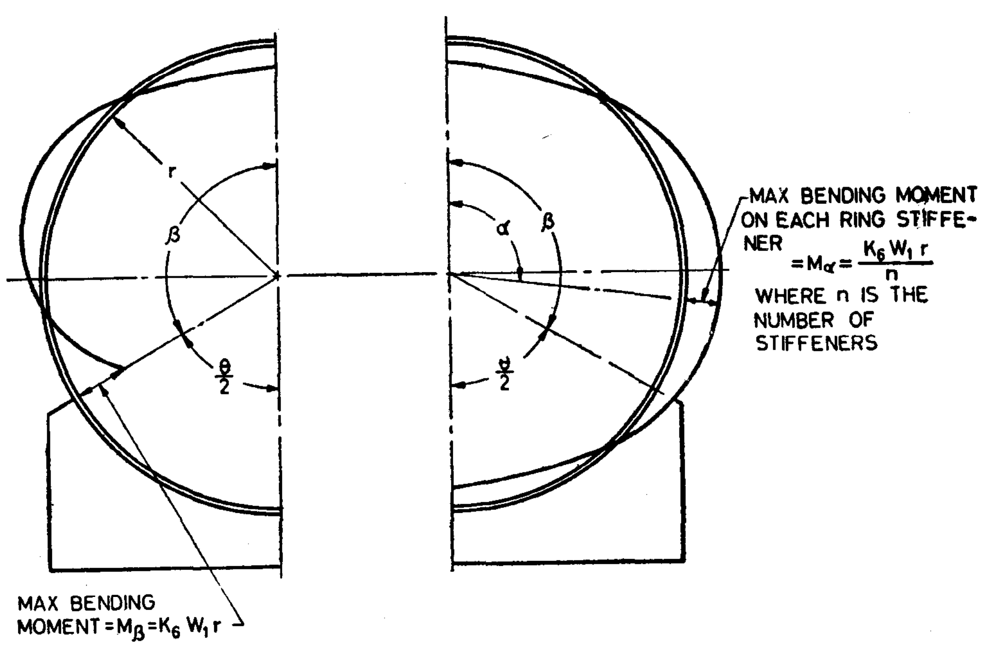
$$\text{at the shell, } f_7 = \frac{C_4K_7W_1rc}{l} - \frac{K_8W_1}{a} \quad \dots (C.19)$$

at the tip of the ring remote from the

$$\text{shell, } f_8 = \frac{C_5K_7W_1rd}{l} - \frac{K_8W_1}{a} \quad \dots (C.20)$$

Values of C_4, C_5, K_5, K_7 and K_8 are given in Table C.6.

The effective cross-sectional area, a, of the stiffener (or stiffeners) and the portion of the



(A) For no Stiffener or for Ring Stiffener in Plane of Saddle

(B) For Ring Stiffeners Adjacent to Saddle

FIG. C.41 CIRCUMFERENTIAL BENDING MOMENT DIAGRAMS

shell which can be assumed to act with them is indicated by the shaded areas in Fig. C.44A, 44B and 44C.

The moment of inertia I is taken about the axis X — X parallel to the axis of the shell and through the centroid of the shaded area.

Positive values denote tensile stresses and negative values denote compression.

The numerical values of the circumferential stresses found as above should not exceed 1·25 times the allowable working stress in tension.

C-4.3.2.8 *Design of saddles* — The width b_1 of steel saddles (*see* Fig. C.36A) should be not less than 10 × the thickness of the shell. It should be increased if the circumferential stresses, found from whichever of the equations (C.15) to (C.20) is applicable, cannot be accepted.

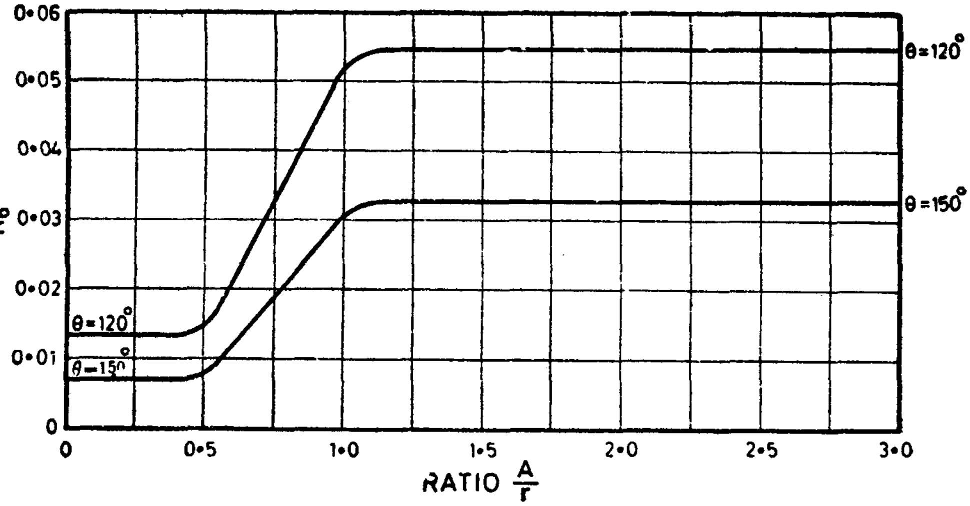


Fig. C.42 Circumferential Bending Moment Constant K_6

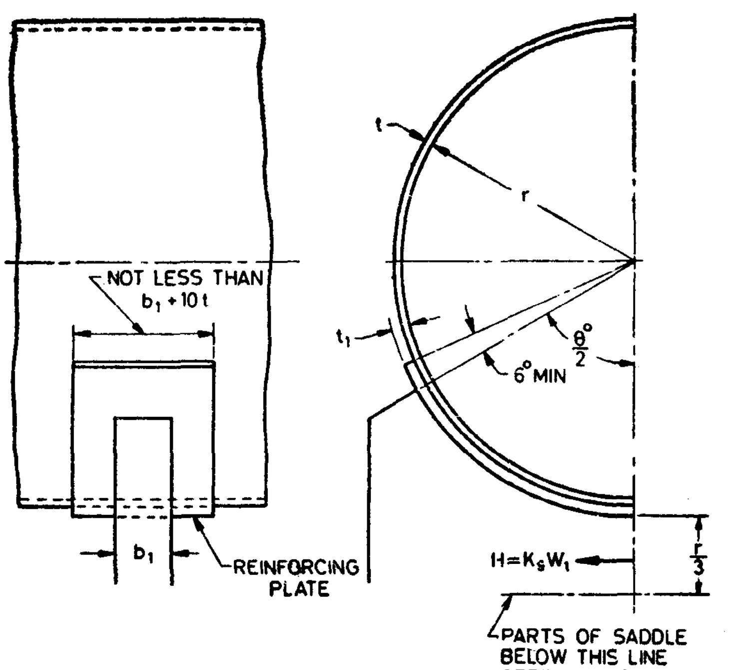
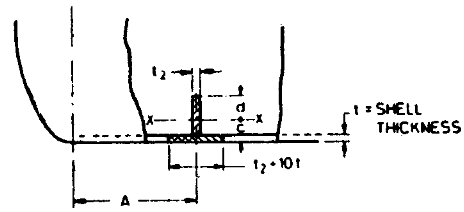
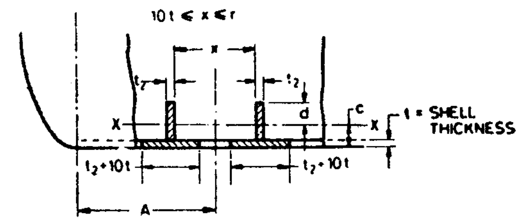


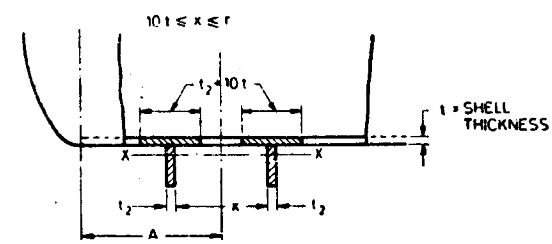
Fig. C.43 Saddle Support and Reinforcing Plate



(A) RING STIFFENER IN PLANE OF SADDLE



(B) INTERNAL RING STIFFENERS ADJACENT TO SADDLE



(C) EXTERNAL RING STIFFENERS ADJACENT TO SADDLE

FIG. C.44 TYPICAL RING STIFFENERS

The minimum section at the low point of a saddle (*see* Fig. C.43) shall resist a force H equal to the sum of the horizontal components of the reactions on one-half of the saddle. The effective cross section resisting this load should be limited to the metal cross section within a distance equal to $r/3$ below the shell and the average direct stress on this cross section should be limited to two-thirds of the allowable design stress.

The force H is equal to $K_9 W_1$

$K_9 = 0{\cdot}204$ for a saddle in which $\theta = 120°$, and $0{\cdot}260$ for a saddle in which $\theta = 150°$.

The upper and lower flanges of a steel saddle should be thick enough to resist the longitudinal bending over the web or webs due to the bearing loads as in any machine support. The web should be stiffened against buckling due to vertical shear forces as for structural beams, and against bending due to longitudinal external loads on the vessel.

One saddle of each vessel should be provided with some form of sliding bearing or rocker in the following cases:

a) When steel saddles are welded to the vessel shell.

b) When large movements due either to thermal expansion or to axial strain in a long vessel are expected.

C-4.3.3 *Ring Supports for Horizontal Vessels* — Ring supports for horizontal vessels, as shown in Fig. C.36B are used where it is important to ensure that the shell of the vessel close to the supports remains round under load. This is usually the case for:

a) thin walled vessels likely to distort excessively due to their own weight, and

b) long vessels requiring support at more than two positions.

The longitudinal bending moments in the shell and the corresponding stresses can be found in the same way as for saddle supports from equations (C.6) to (C.11) in **C-4.3.2**.

The tangential shear stresses in the shell adjacent to the ring support are given by:

$$q = \frac{0{\cdot}319\, W_1}{rt}$$

The required section modulus of the ring support is given by:

$$Z = \frac{K_{10} W_1 r_2}{f}$$

where r_2 is the radius through the centre of gravity of the combined section formed by the ring support and a length of the shell l which can be assumed to act with it, and Z is the least section

TABLE C.6 VALUES OF COEFFICIENTS

(*Clauses* C-4.3.2.6 *and* C-4.3.2.7)

	RING IN PLANE OF SADDLE INTERNAL RING (FIG. C.44A)		RINGS ADJACENT TO SADDLE: Internal Rings (Fig. C.44B)		RINGS ADJACENT TO SADDLE: External Rings (Fig. C.44C)	
	$\theta = 120°$	$\theta = 150°$	$\theta = 120°$	$\theta = 150°$	$\theta = 120°$	$\theta = 150°$
C_4	−1	−1	+1	+1	−1	−1
C_5	+1	+1	−1	−1	+1	+1
K_6	—	—	0·760	0·673	0·760	0·673
K_7	0·052 8	0·031 6	0·057 7	0·035 3	0·057 7	0·035 3
K_8	0·340	0·303	0·263	0·228	0·263	0·228

modulus of this cross section of the ring.

$$l = \sqrt{rt}$$

K_{10} is found from Table C.7.

TABLE C.7 VALUES OF FACTOR K_{10}

Angle, ϕ_1 Degrees	K_{10}	Angle, ϕ_1 Degrees	K_{10}
30	0·075	60	0·035
35	0·065	65	0·031
40	0 056	70	0·026
45	0·049	75	0·021
50	0·044	80	0·016
55	0·039	85	0·015
		90	0·015

Unless a vessel with ring supports works at atmospheric temperature and pressure, at least one ring support shall be provided with some form of sliding bearing at its connection to the foundation or supporting structure.

C-4.3.4 *Leg Supports for Horizontal Vessels* — Leg supports are only permitted for 'small' vessels by the usual codes of practice because of the severe local stresses which can be set up at the connection of the support to the vessel wall.

This connection should be designed for a radial load $= W_1/\cos\phi_1$ (Fig. C.36C) by the method given in **C-3.2.2** and provided with a reinforcing plate to spread the load over a sufficient area to avoid excessive local stresses. For the design reinforcing plates, *see* **C-4.1.6**.

Leg supports may be made of any convenient form, and no definite limit can be given for the maximum size of vessel to which they should be applied.

The permissible values of the local stresses set up near the leg support are laid down in **3.3.2.4** (membrane) and **C-2** (bending).

C-5. THE STABILITY OF THIN-WALLED VESSELS

C-5.1 Introduction and Notation

C-5.1.1 *Introduction* — This section is concerned with the critical loads leading to the collapse of thin shells by buckling due to compression caused by axial force and bending moments. A thin shell is one in which the thickness is less than one-tenth of the radius.

Allowance is made for out-of-roundness but the critical stresses so determined should be used with a suitable safety factor. The data given for the effect of out-of-roundness can also be used to assess the safety factor against collapse of a vessel having known deficiencies.

The effect on stability of the local stresses near the ends of a closed cylinder is neglected.

Some conical shells designed to current codes of practice will be found to have very small safety factors when the method of **C-5.3** is applied to them. This is because these rules are not suitable for all proportions of cones. (For a comparison of current code rules for conical shells with experiment, *see* Reference 5.)

C-5.1.2 *Notation*

Notation	*Unit*	*Description*
a_o	mm	Average maximum radial departure of a cylinder from its true cross section
b	—	Ratio, greatest difference between actual and nominal radii and thickness of shell
D	mm	External diameter of cylinder
D_{Ma}	mm	Major diameter of an out-of-round cylinder
D_{Min}	mm	Minor diameter of an out-of-round cylinder
e	mm	Eccentricity of axial load
E	kgf/mm²	Modulus of elasticity of shell
f_c	kgf/mm²	Critical stress
f'_c	kgf/mm²	Value of f_c for an imperfect shell
f_m	kgf/mm²	Maximum stress due to combined bending and axial loading
f_y	kgf/mm²	Yield stress of material
k_1	—	Factor for failure by 'Euler' buckling under axial load
k_2	—	Factor for failure by local buckling under axial load
k_3	—	Factor for type of edge support
K_u	—	Factor for finding unevenness factor U
l	mm	Length of cylindrical shell
m	—	Ratio of circumferential and axial wave lengths
M	kgf·mm	External moment acting on vessel
N	—	Number of circumferential wave lengths in circumference of vessel
r	mm	External radius of shell
t	mm	Thickness of shell
U	—	Unevenness factor
W	kg	Total axial load on shell
W_o	kg	Critical axial load on a conical shell
α	degrees	Semi-vertex angle of a conical shell
v	—	Poisson's ratio

C-5.1.3 *The Unevenness Factor for Imperfect Cylinders* — The strength of thin cylinders to resist compression due to axial loading is severely affected by out-of-roundness. The article deals with the determination of the basic unevenness factors used in the remainder of this section.

The basic unevenness factor U is given by the equation (*see* Reference 3):

$$U = a_0 m^{1\cdot5} N^2 \left(\frac{t}{r}\right)^2 = K_u . a_0 \left(\frac{t}{r}\right)^2 \quad \text{... (C.21)}$$

where a_0 is the mean radial deviation from a true cylindrical shape (Fig. C.45), N is the number of wavelengths of circumferential waves formed in buckling, and m is the ratio of the circumferential and axial lengths of the wave formed by buckling.

$$m = \frac{\pi}{N} . \frac{r}{l} \quad \text{... (C.22)}$$

$\frac{l}{r} N$ is a function of $\frac{l}{\sqrt{rt}}$

the values of $\frac{l}{r} N$ and the factor K_u can be found from the chart of Fig. C.46 when $\frac{l}{\sqrt{rt}}$ is known.

To use this chart enter the graph at the value of $\frac{l}{\sqrt{rt}}$ on the top left-hand scale.

The intercept on the left-hand curve gives the value of $\frac{l}{r} N$ on the vertical scale. A horizontal line from this intercept to the diagonal line for the given value of r/l gives the value of K_u which is read from the bottom scale. These graphs are drawn to a log-log scale and the scale of a slide rule can be used for interpolation. The dotted line on the chart indicates this procedure for a cylinder in which:

$$\frac{l}{\sqrt{rt}} = 7\cdot8 \text{ and } r/l = 1\cdot36$$

For vlaues of r/l outside the range of the chart, the value of $\frac{l}{r} N$ found from the left-hand curve can be used to find N. The value of m, obtained by substitution in equation C.22, enables equation C.21 to be solved for U when a_0 is known.

$$a_0 = \frac{D_{Max} - D_{Min}}{4} \quad \text{...(C.23)}$$

For new designs, the values of D_{Max} and D_{Min} should be found from the maximum departures from a true cylindrical shape allowed by the specification for the vessel and the amount of any deflections due to external forces found from **C-3.2.3**.

When assessing existing vessels for new duties, D_{Max} and D_{Min} should be found by measurement, but deflections due to external loads present under operating conditions may also have to be considered.

When there are no large deflections due to external loads and ordinary manufacturing imperfections only are present, the following typical values of U may be used:

Case	*Range of Values of U*
Machined cylinders	$1\cdot5 \times 10^{-4}$ to 3×10^{-4}
Cylinders carefully rolled from good plate	3×10^{-4} to 5×10^{-4}
Cylinders rolled from commercial plate	5×10^{-4} to 10×10^{-4}

The 'good plate' in the table above is plate which has been specially flattened before being rolled to a cylindrical form.

C-5.2 Thin Cylinders Under Axial Compression

C-5.2.1 *Initial Development* — A thin cylinder under axial compression may fail in one of the following three ways:

a) By plastic yielding when the stress in the material reaches the yield stress.
b) By buckling of the complete cylinder as a strut (Euler buckling).
c) By local buckling with the formation of axial and circumferential waves on the surface.

Table C.8 gives the conditions for these modes of failure and the transitions between them.

C-5.2.2 *Critical Stress Factors for Axial Compression* — The factor k_1 depends on the end conditions for the cylinder as a whole. Values of k_1 are given in Table C.9.

The factor k_2 depends on the initial imperfections of the cylinder. It is found from the non-dimensional factors $\frac{f_Y}{U.E}$ and $\frac{U.r}{t}$ by means of the graphs of Fig. C.47.

The unevenness factor U is found from the formulae of **C-5.1.3** and the factor K_u from Fig. C.46.

C-5.2.3 *Combined Bending and Direct Axial Stress* — The highest compressive stress occurring in a cylinder subjected to an axial load W and a bending moment M is given by:

$$f_m = \frac{W}{2\pi . rt}\left[1 + \frac{2e}{r}\right] + \frac{M}{\pi r^2 t}$$

M is any superimposed bending moment which may arise from:

a) wind load on a vertical exposed vessel,
b) pipe anchor forces, or
c) weight of contents of a horizontal vessel.

The maximum stress f_m should be limited to the lowest critical stress found as above divided by an appropriate safety factor.

The moment M in the equation above is in kgf.mm.

C-5.3 Stability of Conical Shells

C-5.3.1 *Local Buckling Under Axial Compression* — An ideal right circular frustum of a cone of constant thickness t and semi-vertex angle α will fail by local buckling under a critical load given by:

$$W_0 = \frac{2\pi E t^2 \cos^2\alpha}{\sqrt{3(1-v^2)}}$$

whence $W_0 \simeq 7{\cdot}75 \times 10^4 t^2 \cos^2\alpha$ for mild steel (Reference 4).

For imperfect cones the value of W_0 found as above should be multiplied by the imperfection factor k_2 found as in **C-5.2.2** for the mean value of $\frac{r}{t}$.

For a complete cone this is equal to $\frac{r}{2t}$; for a frustum of radii r_1 and r_2, $\frac{r}{t} = \frac{r_1 + r_2}{2t}$.

The unevenness factor U is found as in **C-5.1.3**, by taking l equal to slant height of the cone or frustum.

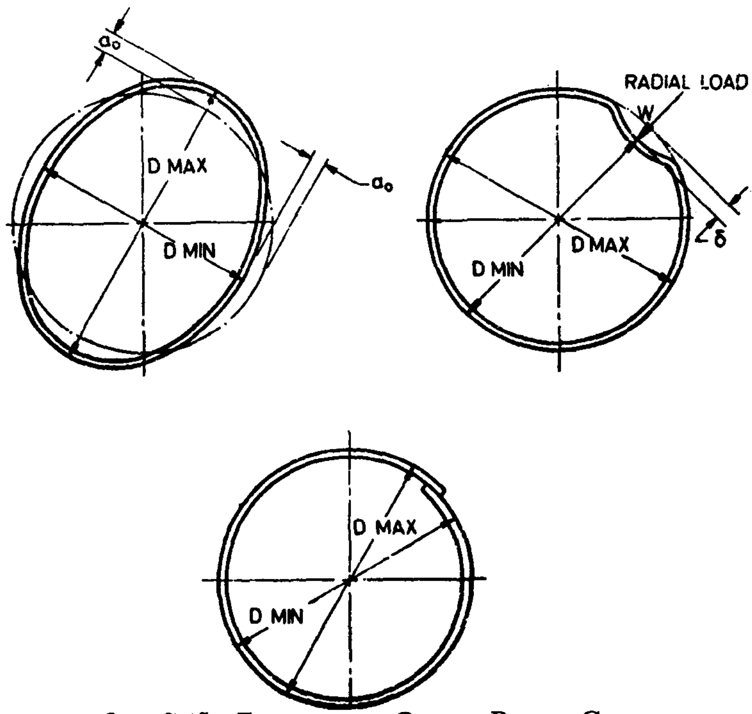
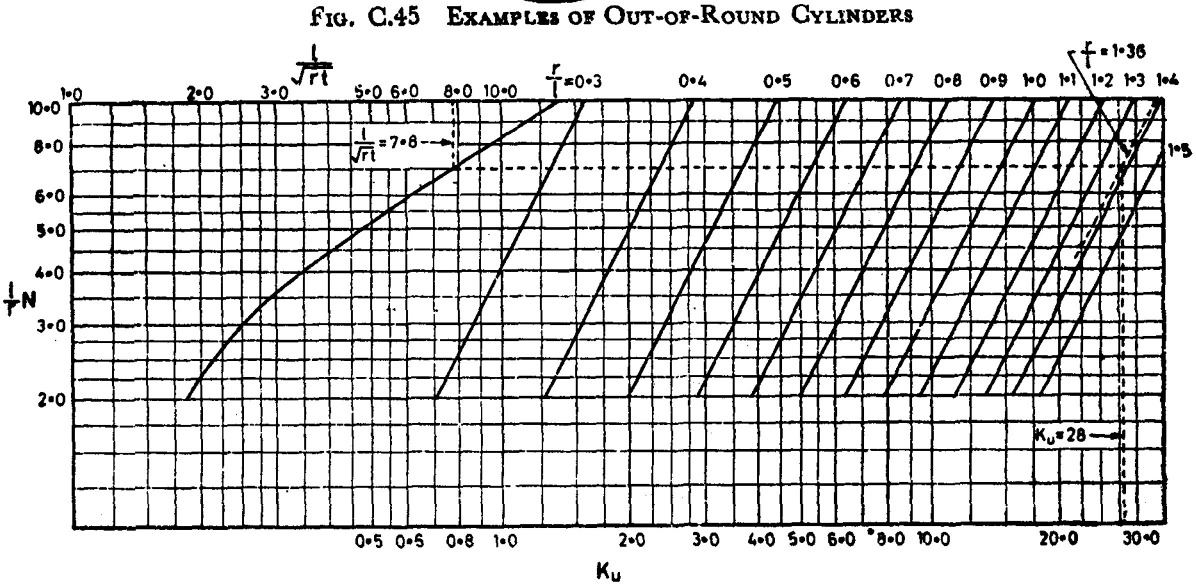


FIG. C.45 EXAMPLES OF OUT-OF-ROUND CYLINDERS



Unevenness Factor $U = K_u\, a_0 \left(\frac{t}{r}\right)^2$

FIG. C.46 CHART FOR FINDING FACTOR K_u

TABLE C.8 COMPARISON OF MODES OF FAILURE

(*Clauses* C-5.1.3 *and* C-5.2.1)

Mode of Failure	Plastic Yielding	Euler Buckling	Local Buckling
Critical stress	$f_c = f_y$	$f_c = \frac{k_1 E}{2} \cdot \frac{\pi^2 r^2}{l^2}$	$f_c = \frac{k_2 E}{\sqrt{3(1-v^2)}} \cdot \frac{t}{r}$
Conditions for transition between modes of failure			
Plastic yielding to Euler Buckling		Euler buckling to local buckling	Plastic yielding to local buckling
$\frac{l}{r} > \pi \sqrt{\frac{k_1 E}{2 f_y}}$		$\frac{t}{r} < \pi^2 \frac{\sqrt{3(1-v^2)}}{2} \cdot \frac{k_1 r^2}{k_2 l^2}$	$\frac{t}{r} < \frac{\sqrt{3(1-v^2)}}{k_2} \cdot \frac{f_y}{E}$
For mild steel		For mild steel	For mild steel
$\frac{l}{r} > 65 \sqrt{k_1}$		$\frac{t}{r} < 8{\cdot}15 \frac{k_1 r^2}{k_2 l^2}$	$\frac{t}{r} < \frac{0{\cdot}001\ 92}{k_2}$

Reference 2, Chapters II and IX; and Reference 3.

TABLE C.9 CRITICAL STRESS FACTOR k_1 FOR AXIAL COMPRESSION

(*Clause* C-5.2.2)

End Condition		
End 1	End 2	k_1
Clamped	Free	0·25
Simply supported	Simply supported	1·0
Clamped	Simply supported	2·0
Clamped	Clamped	4·0

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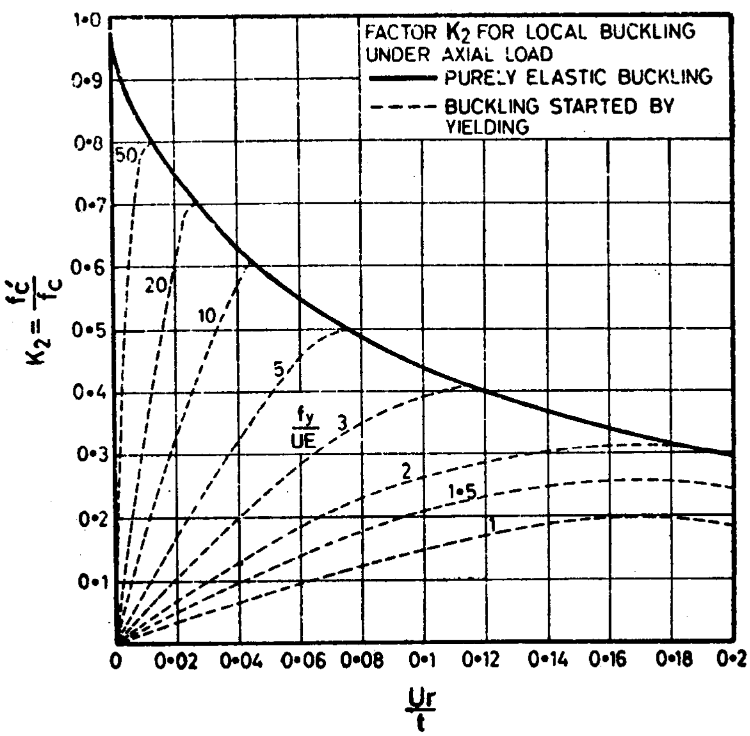

Fig. C.47 Chart for Finding Factor K_2

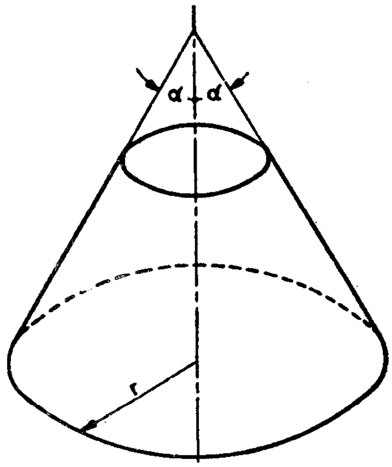

FIG. C.48

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APPENDIX D

(*Clauses* 2.3, 3.1 *and* 3.8.2)

TENTATIVE RECOMMENDED PRACTICE FOR VESSELS REQUIRED TO OPERATE AT LOW TEMPERATURES

D-1. GENERAL

D-1.1 The ductility of some metals, including the carbon and low alloy steels referred to in this standard, is significantly diminished when the operating temperature is reduced below some critical value. The critical temperature, commonly described as the transition temperature, depends upon the material, method of manufacture, previous treatment and the kind of stress system present. Fracture occurs at temperatures above the transition temperature only after considerable plastic strain or deformation. Whilst below the transition temperature, fracture may take place

in a brittle manner with little or no deformation. Brittle fractures are likely to be extensive and may lead to catastrophic fragmentation of a vessel.

D-1.2 It is believed that the transition temperature of any given material is raised as the stress system approaches a uniform triaxial tensile state. For instance, material which has failed by brittle fracture will usually be found to show normal ductility, even at temperatures below that at which failure occurred, in a standard tensile or bend test, but similar specimens, if notched before testing, would be quite likely to break in a brittle manner. Thus constructional features producing a notch effect or sudden change of section are particularly objectionable in vessels designed for low temperature operation, since they may create a state of stress such that the material will be incapable of relaxing high localized stresses by plastic deformation. For this reason the property of interest is described as notch ductility.

D-1.3 Many tests to determine the notch ductility of steels have been proposed but none has as yet been completely correlated with service experience. The most convenient test is as given in IS : 1757-1961*.

D-1.4 In most of the tests currently used to determine notch ductility the transition from ductile to brittle behaviour takes place over a range of temperature rather than at a single temperature. It is considered that an impact value of 2 kgf.m as determined by the method prescribed in IS : 1757-1961* at the service temperature will have adequate notch ductility for use in fusion-welded pressure vessels.

D-1.5 Notch ductility is an extremely variable property of steel and mild steel, in thicker plates, made in accordance with current specifications for steel for pressure vessel construction may show a Charpy 2 kgf.m 'V' notch transition temperature higher than normal atmospheric temperature. The safe record of the use of such steels shows that materials regarded as notch brittle can be used satisfactorily if the design working stresses, construction, and workmanship are suited to the properties of the particular material. Thus it is apparent that notch ductility is not necessarily an absolute requirement for all materials to be used for the manufacture of pressure vessels.

D-1.6 Consideration of service experience and the large amount of experimental work carried out confirms that brittle failures are not likely to occur except when both the following conditions occur simultaneously:

a) The material exhibits very little notch ductility at the service temperature; and
b) A tensile force, which may be produced by applied loads or residual stresses, of a magnitude sufficient to cause plastic deformation is present at an existing crack or other severe notch. A brittle fracture will not propagate unless the general tensile membrane stress is sufficiently high to supply the necessary energy. Thus vessels in refrigerant service will not normally require any special precautions where the operating pressure is temperature dependent and hoop stresses are small at operating temperatures.

It is considered that the first condition will be eliminated when the relevant impact tested material is used; the second condition will not occur in vessels designed and constructed in accordance with the requirements of this standard except possibly adjacent to welded seams in vessels not stress-relieved.

D-1.7 After consideration of these factors, it is recommended that the following minimum requirements should be satisfied in vessels designed to operate at low temperatures. It is recommended that manufacturers carry out preliminary tests to confirm that the properties—especially notch ductility—of the materials used will not be damaged by treatments involved in the fabrication of the vessel. Tests to determine the characteristics of welding electrodes should take into account the effect of variations in welding position and the effect of scatter of results should be considered.

D-2. MATERIALS AND DESIGN STRESSES

D-2.1 Materials and design stresses shall be in accordance with the requirements of Tables D.1 and D.2.

D-2.1.1 Because the liability of a given material to brittle fracture depends on the stress level and in some vessels because of the service conditions pressure at low temperatures is necessarily much lower than that at, for instance 0°C, two cases are considered:

a) That in which the pressure at the sub-zero design temperature is not less than that which would be permitted for the vessel at 0°C by this standard; and
b) That in which the pressure at low temperatures will be considerably below the pressure permitted at 0°C (for example, in refrigerating equipment).

D-2.2 Operating Pressure at Low Temperature Equal to Design Pressure at 20°C — Table D.1 sets out the limits of operating temperature for vessels designed in accordance with **3** at stress levels in accordance with **2.2** (*see also* Table D.2). These limits are dependent on the grade of steel, the thickness of the steel where it is welded and whether the vessel is stress-relieved.

D-2.3 Operating Pressure at Low Temperature Less Than Design Pressure at 20°C — Special considerations govern equipment which normally operates at low temperatures and pressures but is necessarily designed to withstand the pressure which may arise, for instance, during shut-down periods, when the equipment warms up and the vapour pressure of the contents rises.

*Method for beam impact test (V-notch) on steel.

D-2.3.1 Such equipment shall be designed according to **3** using design stresses in accordance with **2.2** (*see also* Table D.2) for the highest pressure which may occur in it. It shall then be verified that the nominal stresses calculated in accordance with **3** do not exceed the appropriate values given in Table D.2 for all combinations of pressure and temperature which may occur at temperatures lower than the limiting value given in Table D.1 appropriate to the proposed material, thickness and whether stress-relieved.

D-2.3.2 If it is found that the stress level at some low temperature is higher than that permitted by Table D.2, the proposed design is unsuitable.

D-3. POST-WELD HEAT TREATMENT

D-3.1 Post-weld heat treatment greatly reduces the liability of ferritic steel equipment to brittle fracture. As indicated in Tables D.1 and D.2 certain combinations of steel, thickness and temperature are only permitted if post-weld heat treatment is applied.

Where post-weld heat treatment is mandatory, it shall be carried out in accordance with **6.12**.

TABLE D.1 MINIMUM ALLOWABLE OPERATING TEMPERATURES

(*Clauses* D-2.1, D-2.2, D-2.3.1, D-3.1, D-5.1 *and* D-6.5)

(*See* Table D.2 for vessels operating under reduced pressure at low temperatures)

Materials: Description	Materials: Type, Reference and Grade	Charpy V-Notch Impact Value as Determined by the Method Given in IS : 1757-1961 at Test Temperature in kgf·m (Average of 3 Specimens)	Thickness mm	Minimum Allowable Operating Temperature °C: Welded Vessels not Stress-Relieved by Heat Treatment (*See also* Table 6.3)	Minimum Allowable Operating Temperature °C: Seamless Vessels, Welded Vessels Stress-Relieved by Heat Treatment and Bolting	Remarks
Carbon steel	Grade 1 of IS : 2002-1962	Not specified	Not exceeding 12	−30	−50	Plate material only
			Not exceeding 18	−20	−40	
			Not exceeding 25	−10	−30	
			Not exceeding 30	0	−20	
			Over 30	0	0	
	Grade 2A of IS : 2002-1962	Not specified	Not exceeding 16	0	−30	Plate material only
	Bars for bolting, material conforming to Grade 1 of IS : 2100-1962	Not specified	—	—	−30	Bolting bars
	Grade 1 of IS : 2100-1962	Not specified	Not exceeding 12	−40	−60	Wrought material only
			Not exceeding 18	−30	−50	
	Class 2 of IS : 2004-1962		Not exceeding 25	−20	−40	
			Not exceeding 30	−10	−30	
			Over 30	−10	−10	
	Class 3 of IS : 2004-1962	Not specified	Not exceeding 12	−30	−50	
			Not exceeding 18	−20	−40	
			Not exceeding 25	−10	−30	
			Not exceeding 30	0	−20	
			Over 30	0	0	
	Grade 2 of IS : 3038-1965	Not specified	—	0	0	Castings
Carbon-manganese steel	Type 2 of IS : 2041-1962 or Grade 2B of IS : 2002-1962	Not specified	Not exceeding 12	−30	−50	Plate material only
			Not exceeding 18	−20	−40	
			Not exceeding 25	−10	−30	
			Not exceeding 30	0	−20	
			Over 30	0	−20	
	20Mn2 of IS : 4367 - 1967	4·8 (Izod) at room temperature	Not exceeding 12	−30	−50	Forgings only
			Not exceeding 18	−20	−40	
			Not exceeding 25	−10	−30	
			Not exceeding 30	0	−20	
			Over 30	0	0	
Impact tested ferritic steel castings	Grade I of IS : 4899-1968	2·1 at −40°C	Not exceeding 30		−20	Castings
			Over 30			
	Grade II of IS : 4899-1968	2·1 at −50°C	Not exceeding 30		−30	
			Over 30			
	Grade III of IS : 4899-1968	2·1 at −60°C	Not exceeding 30		−40	
			Over 30			

D-4. DESIGN

D-4.1 Care should be taken to avoid notches and the use of details which produce local areas of high stress, for example, lugs, gussets producing discontinuous stiffening, and sudden change in section. Rings for supporting internal equipment or lagging should be continuous.

Vessels which will be subject to frequent fluctuations in temperature of appreciable magnitude should be the subject of special consideration (for example, refrigeration vessels where low temperature liquid refrigerant is suddenly replaced by warm refrigerant vapour at regular intervals).

D-5. WELD METAL AND HEAT AFFECTED ZONE

D-5.1 Charpy V-notch impact tests shall be made on specimens cut from the weld and the heat affected zones when the design temperature is less than 0°C and operating conditions lie outside the limits permitted in Tables D.1 and D.2. Impact tests shall be carried out in accordance with IS : 1757-1961*. The specimen shall show a minimum Charpy V-notch impact strength of 2·8 kgf·m (taken as an average of three specimens with no individual value less than 2 kgf.m).

*Method for beam impact test (V-notch) on steel.

D-6. MANUFACTURE AND WORKMANSHIP

D-6.1 All cut edges should be machined or ground where necessary to remove the effect of previous shearing, chipping or flame-cutting.

D-6.2 The ends of branch pipes and other openings in the vessel shell should be ground to a smooth radius after all welding is complete.

D-6.3 Any arc flashes should be ground out and welds used for the attachment of erection cleats should be ground flush with the plate surface.

D-6.4 It is suggested that portions of vessels incorporating connections or access openings larger than 250 mm bore, or complicated support details, should be stress-relieved as sub-assemblies if the vessel is not to be subsequently stress-relieved. Marking of the vessel or components by hard stamping shall be avoided.

D-6.5 In cases where temperatures given in Tables D.1 and D.2 coincide or the ranges overlap the values given in Table D.1 govern. At all lower temperatures Table D.2 governs.

TABLE D.2 ALLOWABLE OPERATING TEMPERATURE/STRESS CONDITION FOR VESSELS WHERE RESTRICTIONS GIVEN IN TABLE D.1 ARE NOT SATISFIED

(*Clauses* D-2.1, D-2.2, D-2.3.1, D-2.3.2, D-3.1, D-5.1 *and* D-6.5)

(Applicable to cases where pressure is due solely to vapour pressure of contents)

Plate Thickness mm	Maximum Allowable Stress at Temperature, kgf/mm^2													
	Welded Vessels not Stress-Relieved by Heat Treatment							Seamless Vessel and Vessels Stress-Relieved by Heat Treatment						
	−60°C	−50°C	−40°C	−30°C	−20°C	−10°C	0°C	−60°C	−50°C	−40°C	−30°C	−20°C	−10°C	0°C
Not exceeding 12	1·05	1·41	1·76	2·10	*	*	*	2·46	2·81	*	*	*	*	*
Not exceeding 18	0·70	1·05	1·41	1·76	2·10	*	*	2·10	2·46	2·81	*	*	*	*
Not exceeding 25	0·35	0·70	1·05	1·41	1·76	2·10	*	1·76	2·10	2·46	2·81	*	*	*
Not exceeding 30	—	0·35	0·70	1·05	1·41	1·76	2·10	—	1·76	2·10	2·46	2·81	*	*
Over 30	Post-weld heat treatment required							—	—	1·76	2·10	2·46	2·64	2·81

Note—The above table applies in the case of vessels where the vapour pressure/temperature characteristics of the fluid are such that the design stresses listed above are not exceeded at any temperature below the values given in Table D.1 for the corresponding material.

Stress values for intermediate temperatures may be obtained by linear interpolation.

*Stress values given in Table A.1 shall apply.

APPENDIX E

(*Clauses* 3.1, 3.1.3.2 *and* 3.8.2)

TENTATIVE RECOMMENDED PRACTICE TO AVOID FATIGUE CRACKING

E-1. GENERAL

E-1.1 During service, important parts of pressure vessels may be subjected to cyclic or repeated stresses. Such stresses can be caused by the following:

a) Periodic temperature transients,
b) Restriction of expansion or contraction during normal temperature variations,
c) Applications or fluctuations of pressure,
d) Forced vibrations, and
e) Variations in external loads.

Fatigue cracking will occur during service if endurance limit of the material is exceeded for the particular level of cyclic or repeated stress.

E-1.2 When the expected number of cycles of stress during the service life of any integral part

of a pressure vessel may exceed the endurance limit, the level of cyclic stress and/or the expected number of cycles should be reduced to fall reasonably within the limit.

E-1.3 Corrosive conditions are detrimental to the endurance of the vessel material. Fatigue cracks may occur under such conditions at low levels of fluctuation of applied stress. Since the tensile strength of a steel has little or no effect upon the fatigue strength under corrosive conditions the use of high strength steels in severe corrosion fatigue service will offer no advantage unless the surface is effectively protected from the corrosive medium. Where corrosion fatigue is anticipated it is especially desirable to minimize the range of cyclic stresses and carry out inspection at sufficiently frequent intervals to establish the pattern of behaviour.

E-1.4 A detailed analysis of the cyclic stresses in a pressure vessel and interpretation in terms of satisfactory service life is usually tedious and time consuming. When such estimates are required, the purchaser should inform the manufacturer. The manufacturer should arrange for the calculations to be made, the purchaser having access to any part of the calculations relating to the final assessment.

E-1.5 There is a lack of data on the influence of creep on the endurance of the construction material under cyclic stress. Where a pressure vessel is intended for cyclic operation within the creep range of the material, the range conditions should be agreed between the purchaser and the manufacturer having regard to the available service experience and experimental information.

E-1.6 The following notes relate to pressure vessels which operate at temperatures below the creep range of the material of construction:

a) In general, a detailed analysis need not be made when the design is based on previous and satisfactory experience of strictly comparable service;

b) A fatigue test or tests have been made to demonstrate the reliability of the design;

c) The recommendations which are detailed in the following parts of this section are satisfied; and

d) Where strains have been determined experimentally and shown to be below the endurance limit for the required life.

E-2. PRESSURE CYCLING

E-2.1 A cycle of pressure loading is represented by either each loading and unloading of a vessel or any single pulsation or fluctuation of pressure.

E-2.2 For a vessel which operates at constant pressure and at a steady temperature below the creep range for the material, the expected number of cycles N due to start up and shut down during the life of the vessel should not exceed:

$$N = \left[\frac{1{\cdot}4(3\,000 - T)}{2Kf_r - f} \right]^2 \qquad \dots \quad (E.1)$$

where

T = the temperature in °C corresponding to application of the cyclic or repeated stress;

f = the design stress in kgf/mm² at a temperature of T°C;

K = the theoretical stress or strain concentration factor of any opening, attachment, etc; and

f_r = the range of nominal cyclic stress in kgf/mm².

E-2.3 Where the stress concentration factor K is not known, a value of 4 may be assumed. In no case shall K be taken as less than 2.

E-2.4 For a pressure vessel which is subjected to pressure fluctuations in addition to the conditions defined in **E-2.2**, the requirement is that:

$$\frac{n_1}{N_1} + \frac{n_2}{N_2} + \frac{n_3}{N_3} + \frac{n_4}{N_4} + \dots \text{etc} \leqslant 1{\cdot}0 \dots \quad (E.2)$$

where

n_1, n_2, n_3, n_4, etc, are the expected numbers of cycles of stress for the ranges of pressure fluctuations; and

N_1, N_2, N_3, N_4, etc, are the limiting numbers of cycles calculated by equation (E.1) for the corresponding ranges of cyclic stress (ranges which give $\frac{2Kf_r}{f} \leqslant 1{\cdot}1$ may be neglected).

E-2.5 The ratio of the expected number of cycles to the limiting number of cycles of stress for start-ups and shut-downs of the pressure vessel should be included in equation E.2. However, cycles due to pressure tests can be neglected.

E-3. CYCLIC THERMAL STRESSES

E-3.1 Pressure vessels which operate at elevated or sub-zero temperatures should be heated or cooled slowly and should be efficiently lagged to minimize temperature gradients in the shells. Rapid changes of shell temperature should be avoided during service.

The vessels should be able to expand and contract without undue restraint.

E-3.2 Provided the above conditions are observed estimates of thermal stresses due to temperature changes need not be specially considered. Where slow rates of heating and cooling cannot be employed or temperature transients during service may cause rapid local heating or cooling, the following limitations are recommended:

a) During start-up and shut-down the difference in temperature within a distance equal to twice the thickness of the shell should not exceed 60°C near discontinuities or 150°C at uniform sections.

b) Temperature differences due to temperature transients repeated periodically during service should be limited to similar levels.

E-4. FORCED VIBRATIONS

E-4.1 Pulsations of pressure, wind excited vibrations or vibrations transmitted from plant (that is, rotating or reciprocating machinery) may cause vibrations of piping or local resonance of the shell of a pressure vessel. In most cases these cannot be anticipated at the design stage. It is therefore advisable to make an examination of plant following initial start-up. If such vibration occurs and is considered to be excessive, the source of the vibration should be isolated or stiffening, additional support or damping introduced at the location of the local vibration.

E-5. FINISH OF PRESSURE VESSELS

E-5.1 Where a pressure vessel is intended to operate under cyclic load during service, fillet welds and irregularities should be dressed smooth. Any square edges at junctions between branches and the inside surface of the shell should be radiused.

APPENDIX F

(*Clause* 3.3.3)

ALTERNATE METHOD FOR DETERMINING SHELL THICKNESSES OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE BY USE OF CHARTS

F-1. NOTATION

F-1.1 The following notation is used in the design of spherical and cylindrical shells subject to external pressure:

A and B = Factors obtained from the appropriate chart for shell thickness for vessels under external pressure.

D_o = Outer diameter in mm.

L = Effective length (*see* Fig. F.1) in the case of cylindrical shells it is the maximum of the following values and is measured parallel to the axis of the shell in mm:

1) The distance between head bend lines plus one-third the depth of each head, when no stiffening rings are present.
2) The maximum centre distance between two adjacent stiffening rings.
3) The distance from the centre of the nearest stiffener ring to the head bend line plus one-third the depth of the head.

R_i = Inside radius of spherical shell in mm.

p = Design pressure in kgf/cm².

t = Minimum thickness of shell plates in mm, exclusive of corrosion or other allowances.

F-2. CYLINDRICAL SHELLS

F-2.1 The required thickness of a cylindrical shell under external pressure determined as follows:

Step 1—Assume a value for t. Determine the ratio L/D_o and D_o/t.

Step 2—From the chart determine the intersection of the lines representing L/D_o and D_o/t.

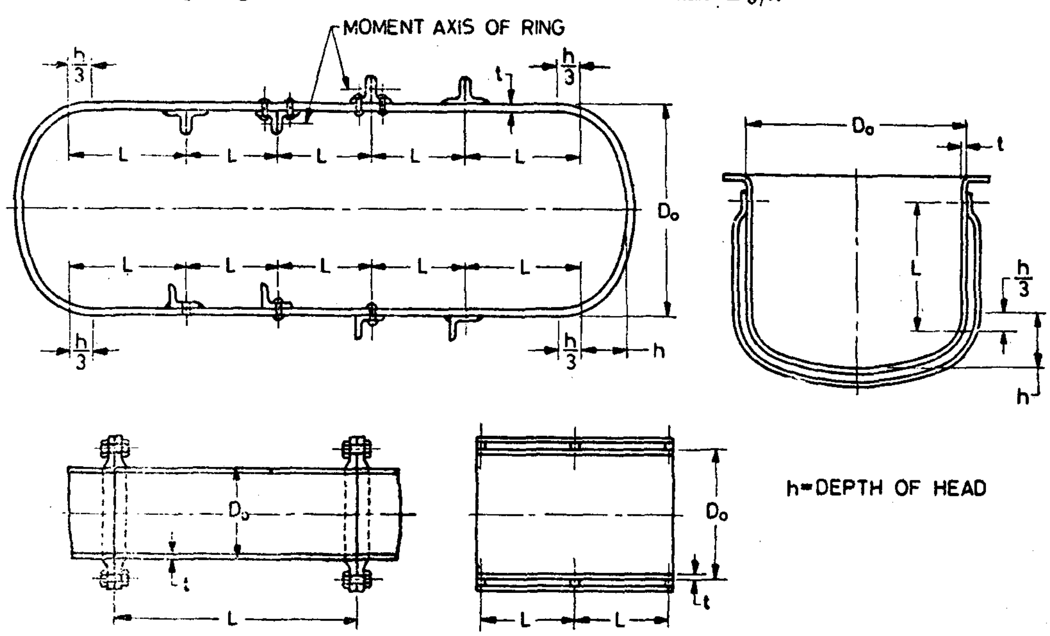


FIG. F.1 EFFECTIVE LENGTH OF A CYLINDRICAL VESSEL UNDER EXTERNAL PRESSURE

Step 3—From this intersection point move vertically to the material line for the design temperature.

Step 4—Find the value of Factor B corresponding to this point of intersection. Compute the allowable working pressure p_a by formula $p_a = \frac{B}{14{\cdot}22 D_o/t}$ kgf/cm² and compare with p. Choose a value of t that will make $p_a \geqslant p$.

F-3. SPHERICAL SHELLS

F-3.1 The required thickness of a spherical shell under external pressure determined as follows:

Step 1—Assuming a value of t, determine the ratios of R_1/t and $R_1/100\,t$.

Step 2—Enter the left-hand side of the chart at the value of $R_1/100\,t$ determined from Step 1 and move horizontally to the line marked ' Sphere Line '.

Step 3—From this intersection move vertically to the material line for the design temperature.

Step 4—Find the value of Factor B corresponding to this point of intersection.

Step 5—Compute the allowable working pressure p_a by the formula $p_a = \frac{B}{14{\cdot}22 R_1/t}$ kgf/cm² and compare with p. Choose a value of t that will make $p_a \geqslant p$.

F-4. STIFFENING RINGS FOR VESSELS UNDER EXTERNAL PRESSURE

F-4.1 Intermediate stiffening rings composed of structural shapes welded to the inside or outside of the shell shall have a moment of inertia about its neutral axis through the centre of gravity section parallel to the axis of the shell, I_s not less than that determined by the formula:

$$I_s = \frac{D_o^2 L\ (t + A_s/L) \times \text{Factor } A}{14 \times 10^4} \quad \ldots \text{F.1}$$

where

I_s = required moment of inertia of the stiffening ring in mm⁴;

A_s = cross-sectional area of stiffening ring mm²; and

L = one-half the distance from the centre line of one stiffening ring to the next line of support on one side, plus one-half of the centre line distance to the next line, if any on the other side of the ring. All the distances are parallel to the axis of the shell and are in mm.

a) Line of support is (*see* Fig. F.1):

1) another stiffening ring,

2) a circumferential connection to a jacket, and

3) a circumferential line on a head at one-third the depth of the head from the head bend line.

The required moment of inertia for a stiffening ring shall be determined as follows:

Step 1—Select a member to be used for the stiffening ring. Let its moment of inertia be I.

Step 2—Calculate Factor B by the formula

$$\text{Factor} \quad B = \frac{pD_o}{t + \frac{A_s}{L}} \times 14{\cdot}22 \quad \ldots \text{F.2}$$

and find the point corresponding to this value of B on the material line for the design temperature.

Step 3—Find the value of Factor A corresponding to this point on the material line.

Step 4—Determine the required moment of inertia I_s from equation (F. 1) using the value of that factor A as determined above. Compare this value of I_s with I and choose a section such that its moment of inertia is greater than I_s.

b) *See* **3.3.3.4** (c).

c) *See* **3.3.3.4** (d).

d) *See* **3.3.3.4** (e).

e) *See* **3.3.3.5**.

F-5. CHARTS FOR DETERMINING SHELL THICKNESSES OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE

Fig. F.2 Carbon and low alloy steel

Fig. F.3 04Cr19Ni9 Type of stainless steel

Fig. F.4 Austenitic stainless steels other than type 04Cr19Ni9

Fig. F.5 07Cr13 Type of stainless steel

Fig. F.6 99·5 Percent aluminium (Grade IB)

Fig. F.7 Aluminium alloy (Grade N3)

Fig. F.8 Al-Mg (2% Mg) Alloy (Grade N4)

Fig. F.9 Al-Mg (3·5% Mg) Alloy (Grade N5)

Fig. F.10 Al-Mg (4·5% Mg) Alloy (Grade N8)

Fig. F.11 Copper (*see* IS : 1972-1961)

Fig. F.12 Aluminium bronze (*see* Grade ISABZT—IS : 1545-1960)

Fig. F.13 70-30 Copper nickel alloy (*see* Grade CuNi31Mn1 Fe of IS : 2371-1963)

Fig. F.14 Nickel

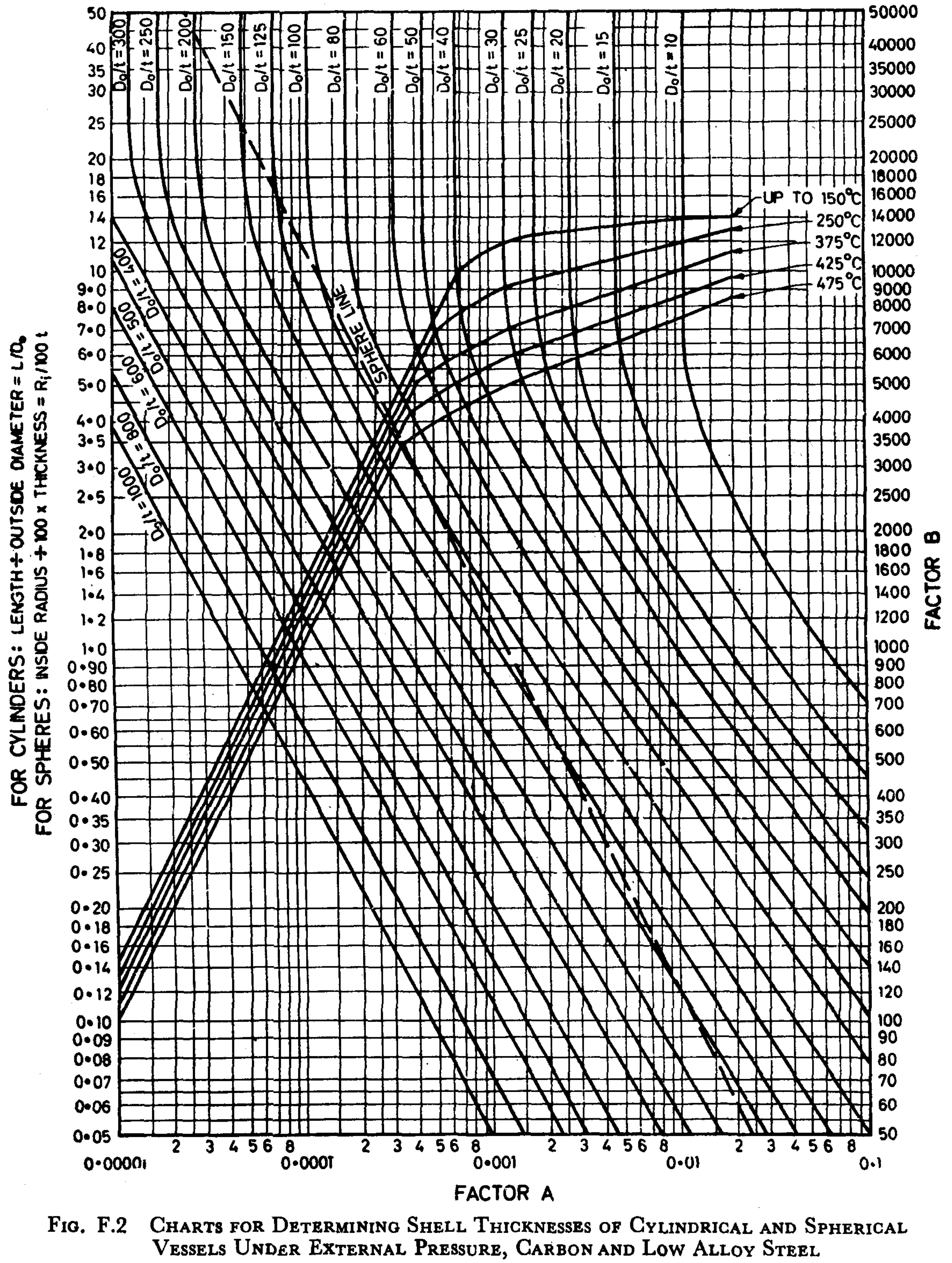


FIG. F.2 CHARTS FOR DETERMINING SHELL THICKNESSES OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE, CARBON AND LOW ALLOY STEEL

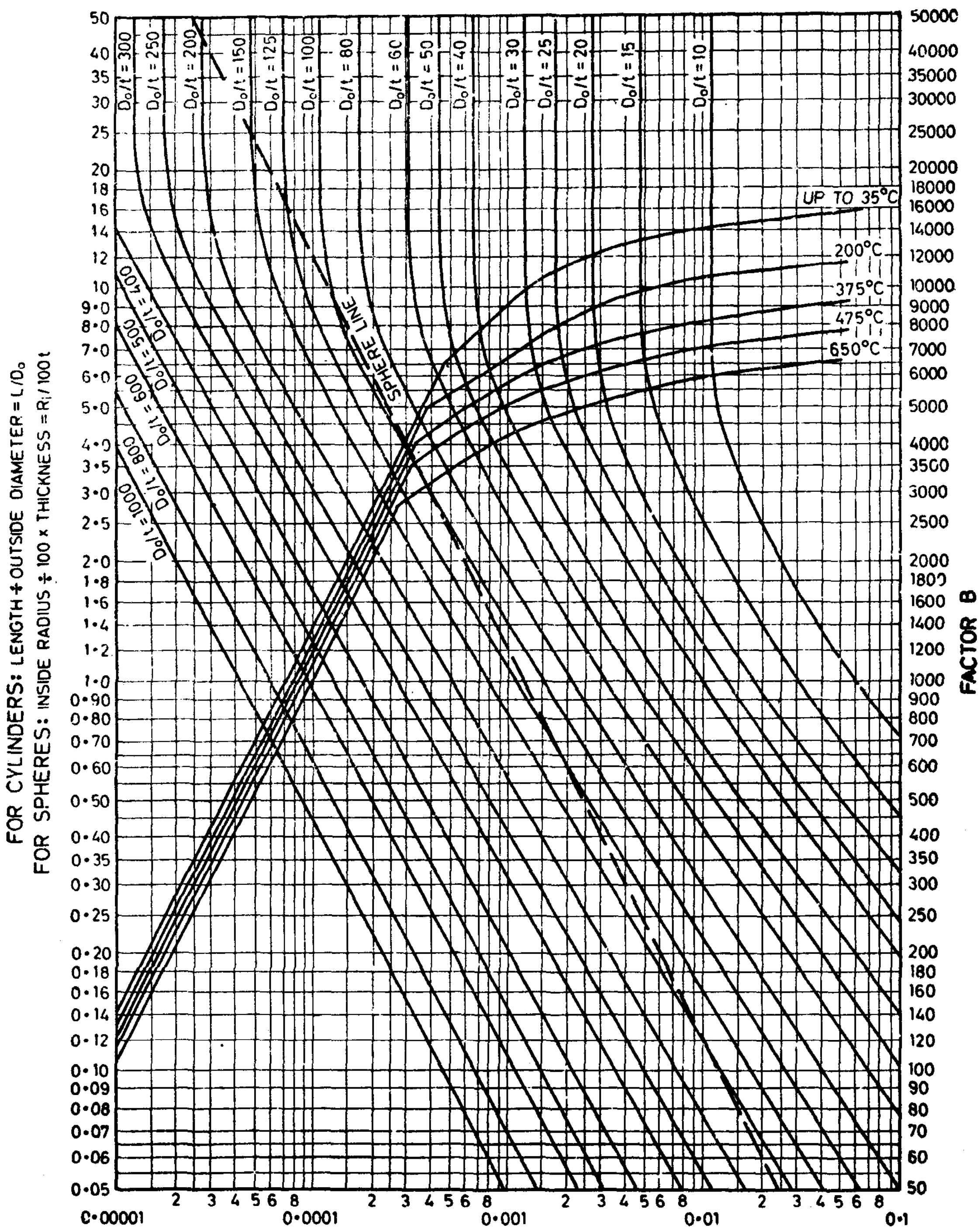


FIG. F.3 CHARTS FOR DETERMINING SHELL THICKNESSES OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE, 04Cr19Ni9 TYPE OF STAINLESS STEEL

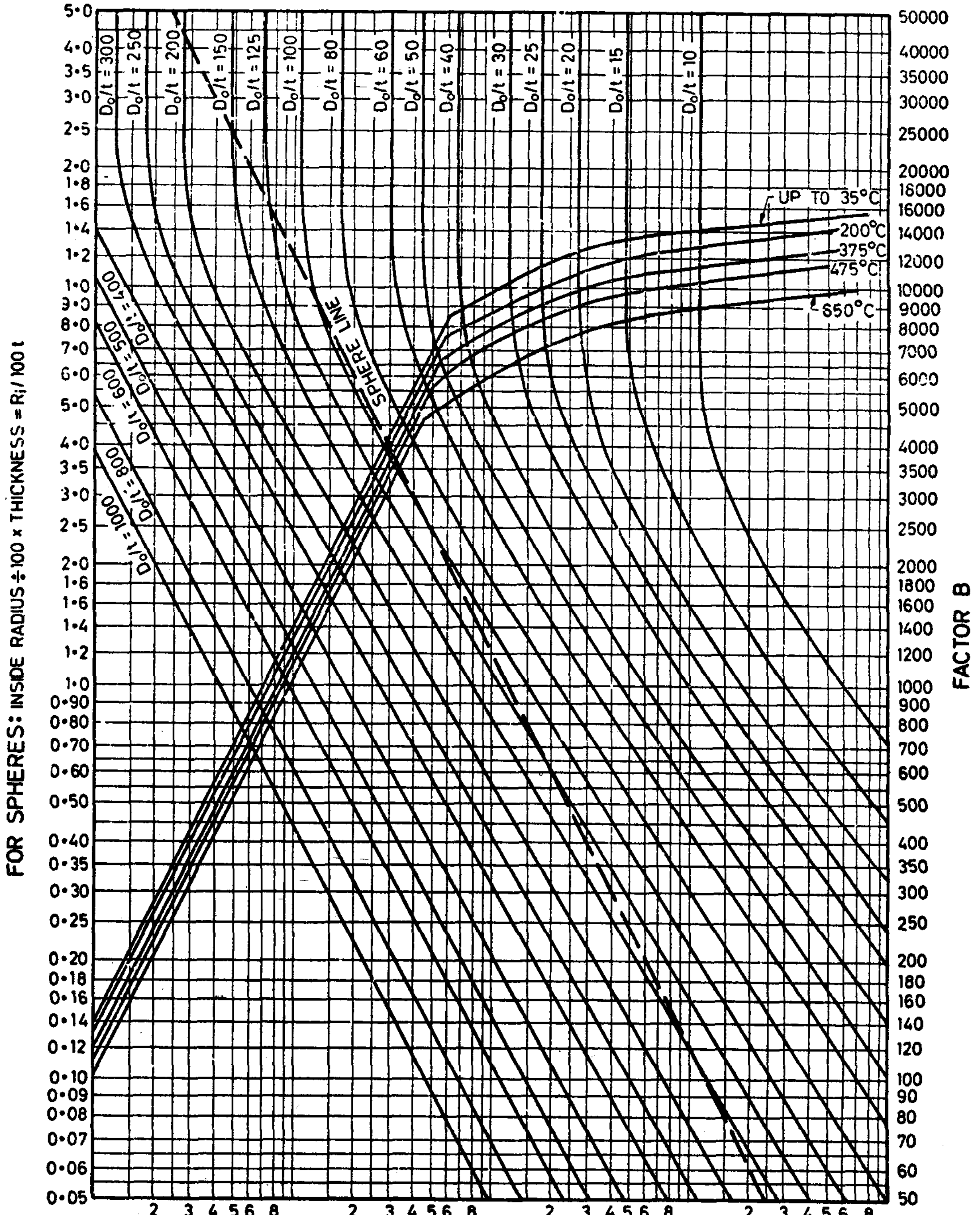


FIG. F.4 CHARTS FOR DETERMINING SHELL THICKNESSES OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE, AUSTENITIC STAINLESS STEELS OTHER THAN TYPE 04Cr19Ni9

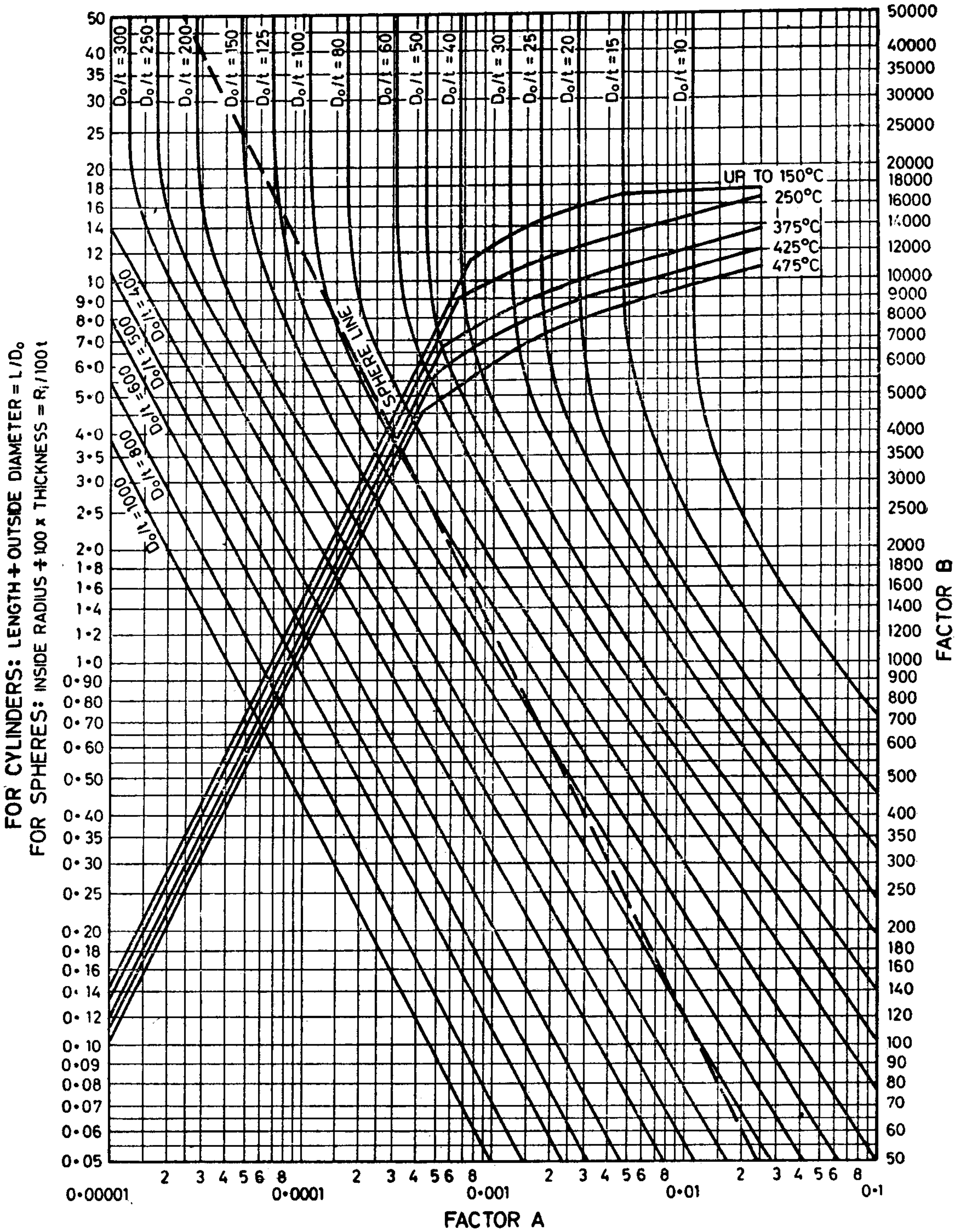


FIG. F.5 CHARTS FOR DETERMINING SHELL THICKNESSES OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE, 07Cr13 TYPE OF STAINLESS STEEL

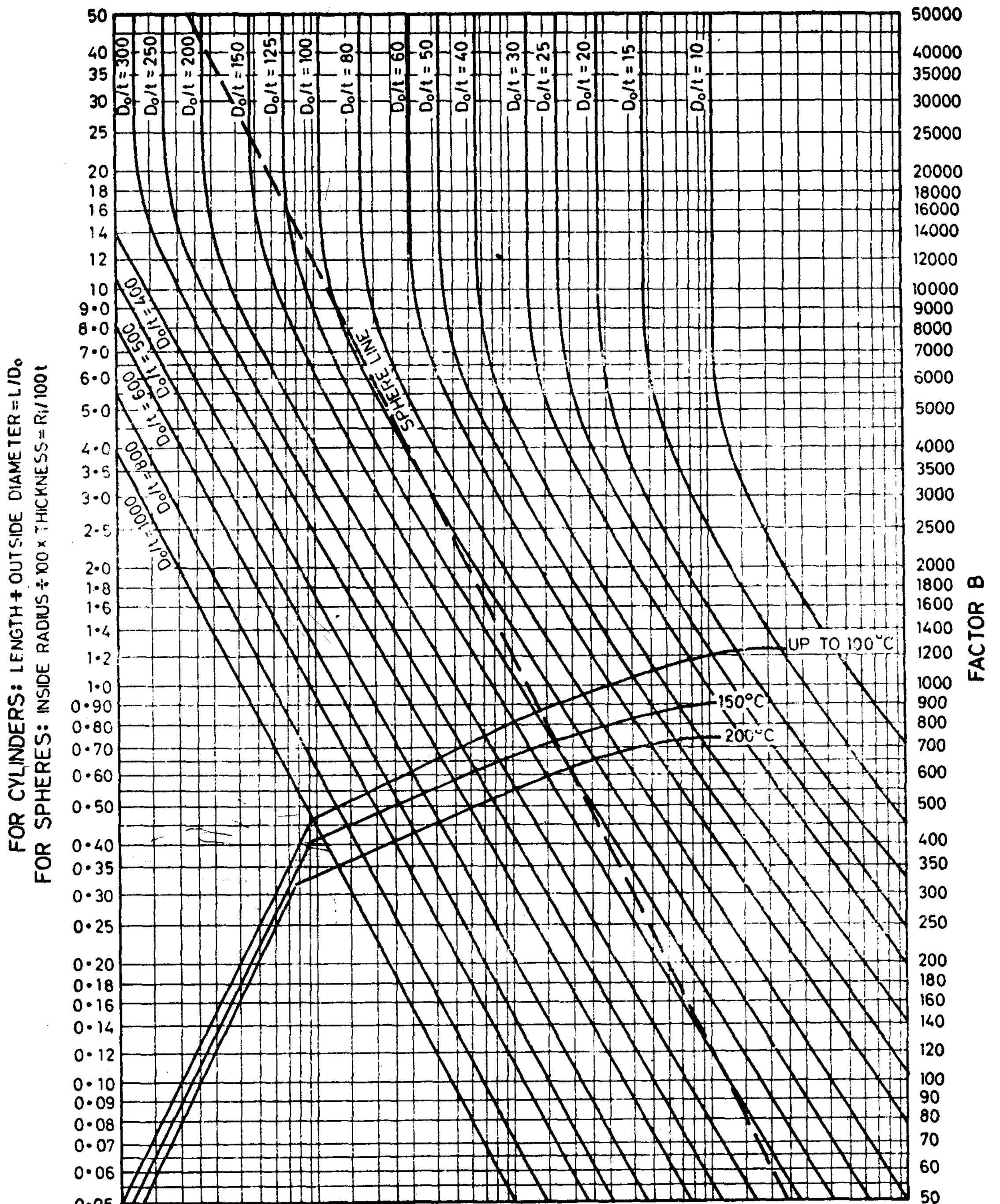


FIG. F.6 CHARTS FOR DETERMINING SHELL THICKNESSES OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE, 99·5 PERCENT ALUMINIUM (GRADE IB)

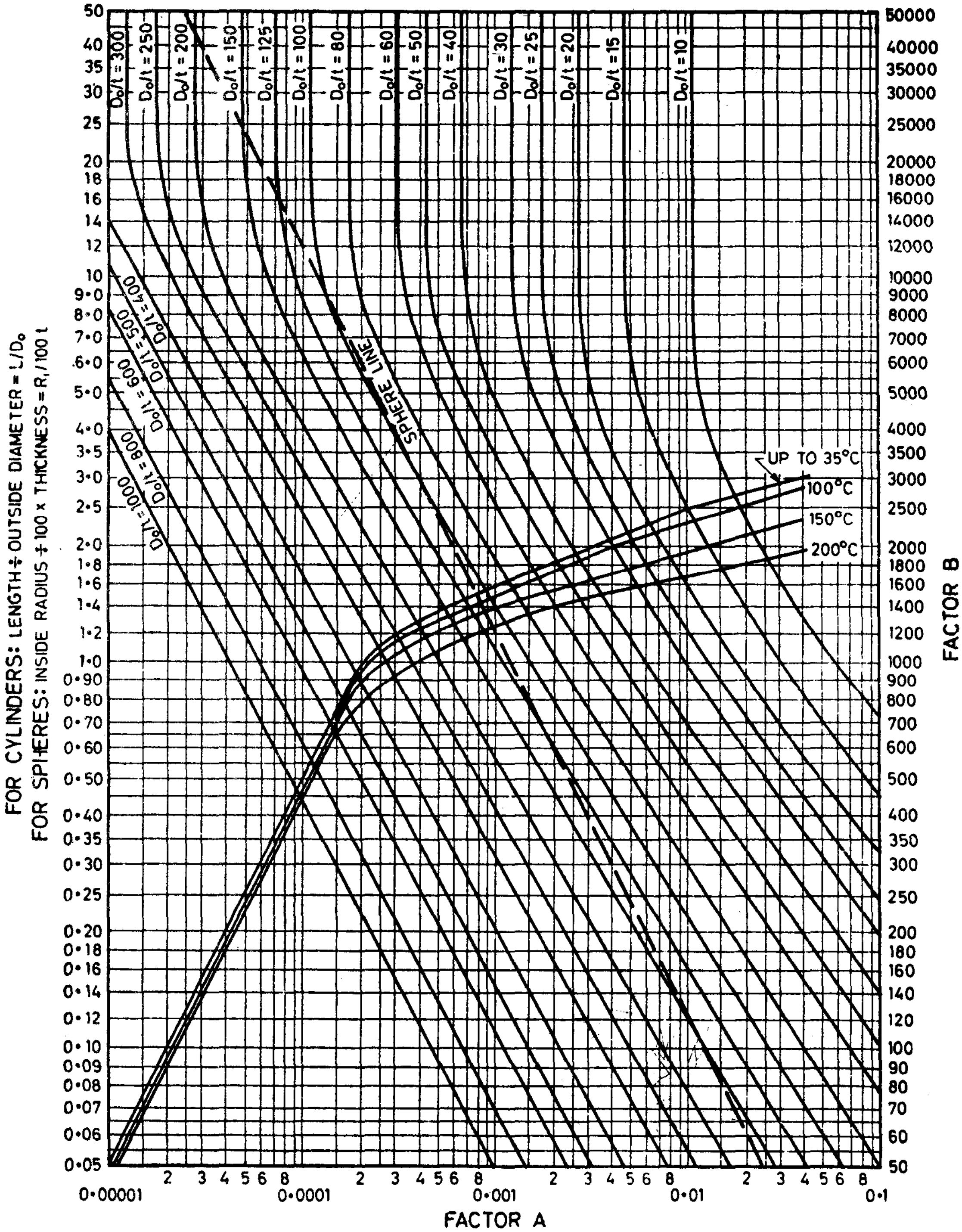


FIG. F.7 CHARTS FOR DETERMINING SHELL THICKNESSES OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE, ALUMINIUM ALLOY (GRADE N3)

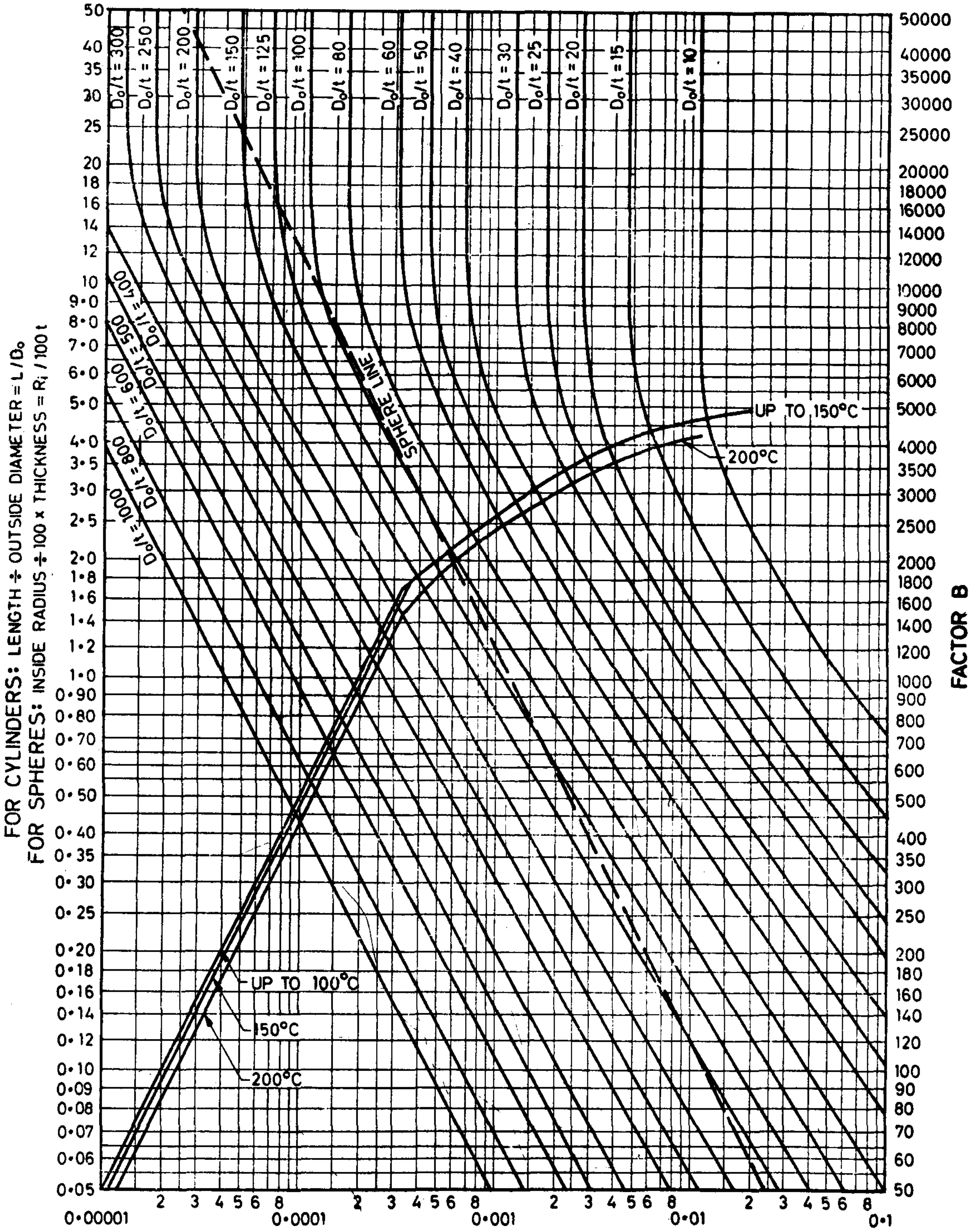


FIG. F.8 CHARTS FOR DETERMINING SHELL THICKNESSES OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE, Al-Mg (2% Mg) ALLOY (GRADE N4)

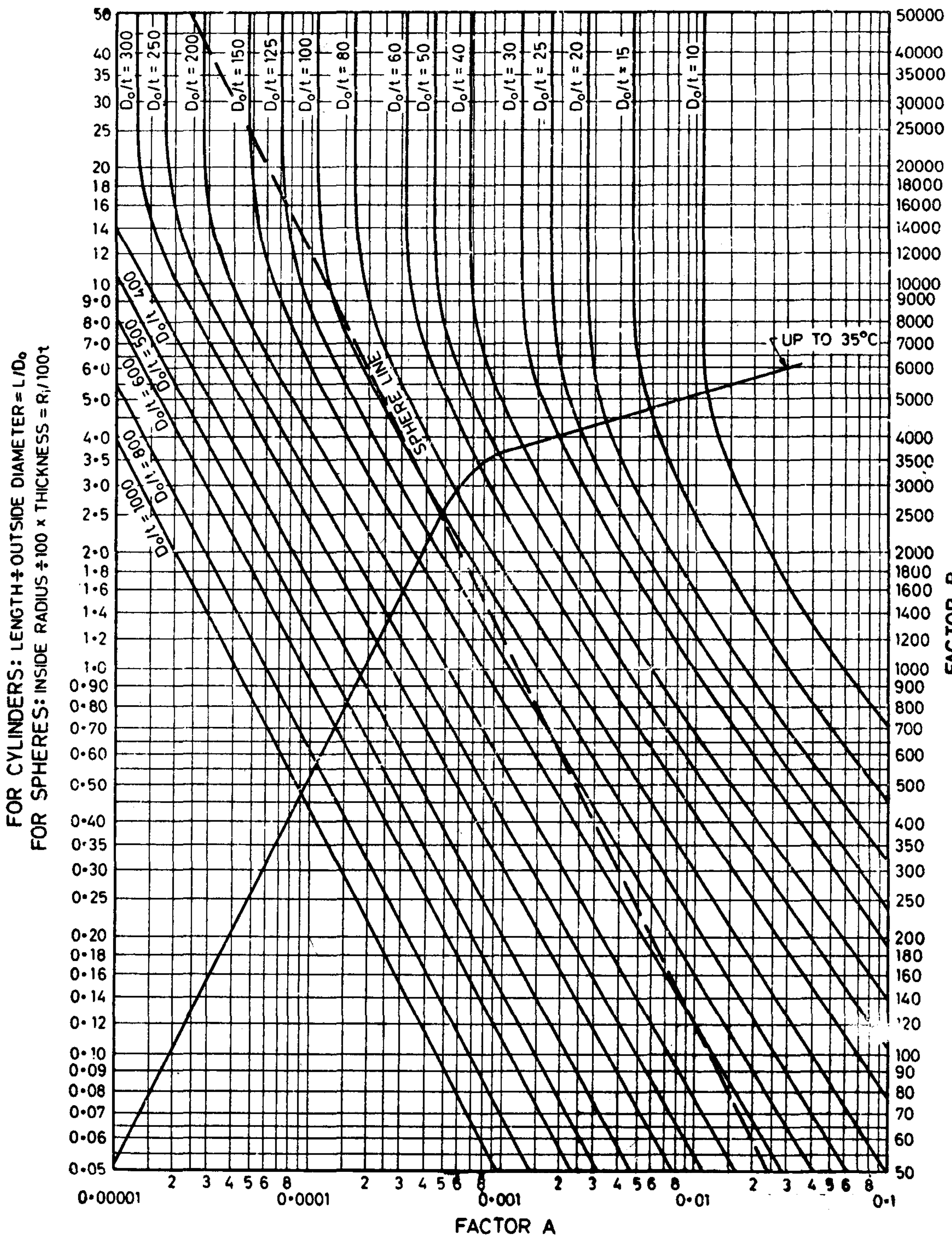


FIG. F.9 CHARTS FOR DETERMINING SHELL THICKNESSES OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE, Al-Mg (3·5% Mg) ALLOY (GRADE N5)

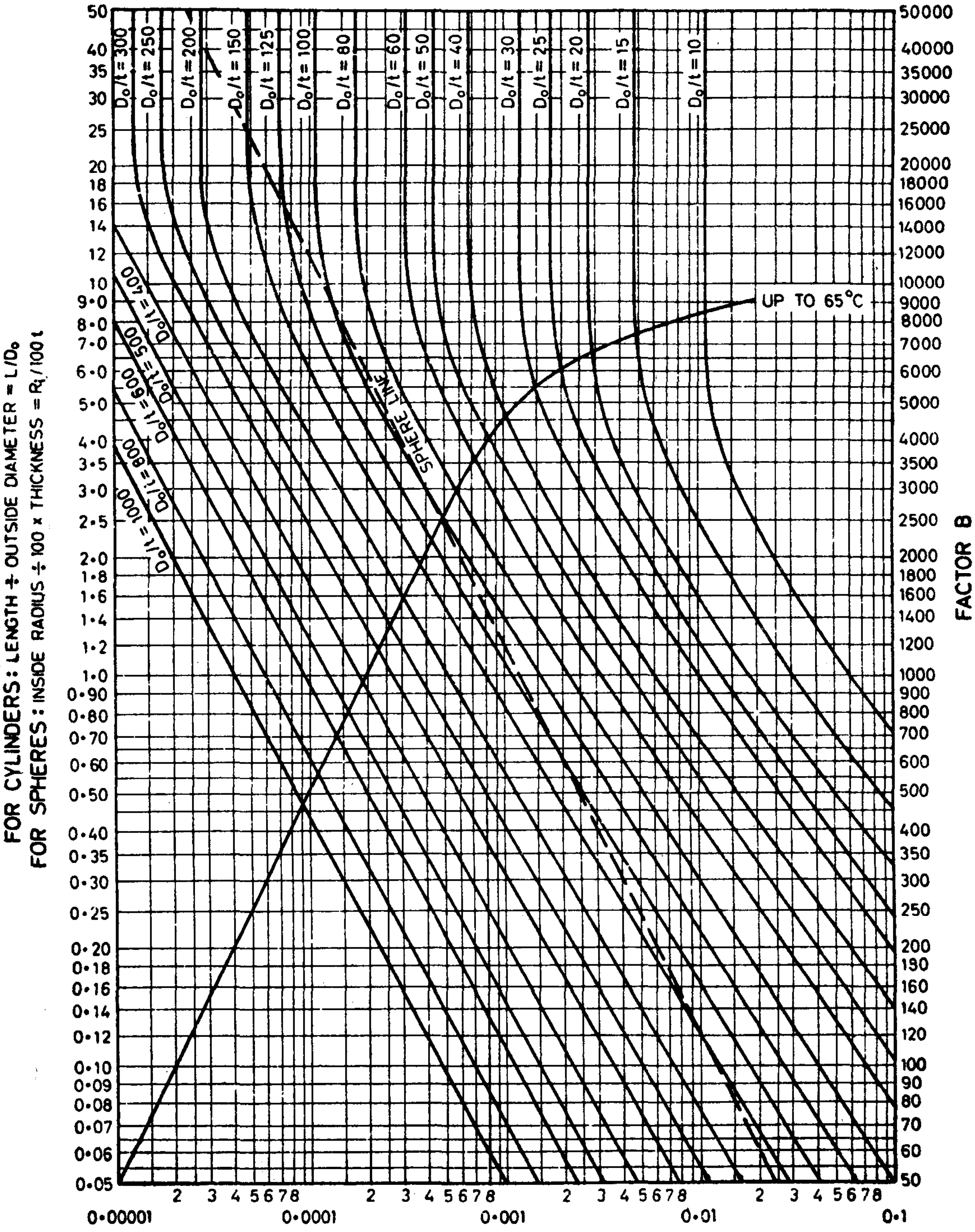


FIG. F.10 CHARTS FOR DETERMINING SHELL THICKNESSES OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE, Al-Mg (4·5% Mg) ALLOY (GRADE N8)

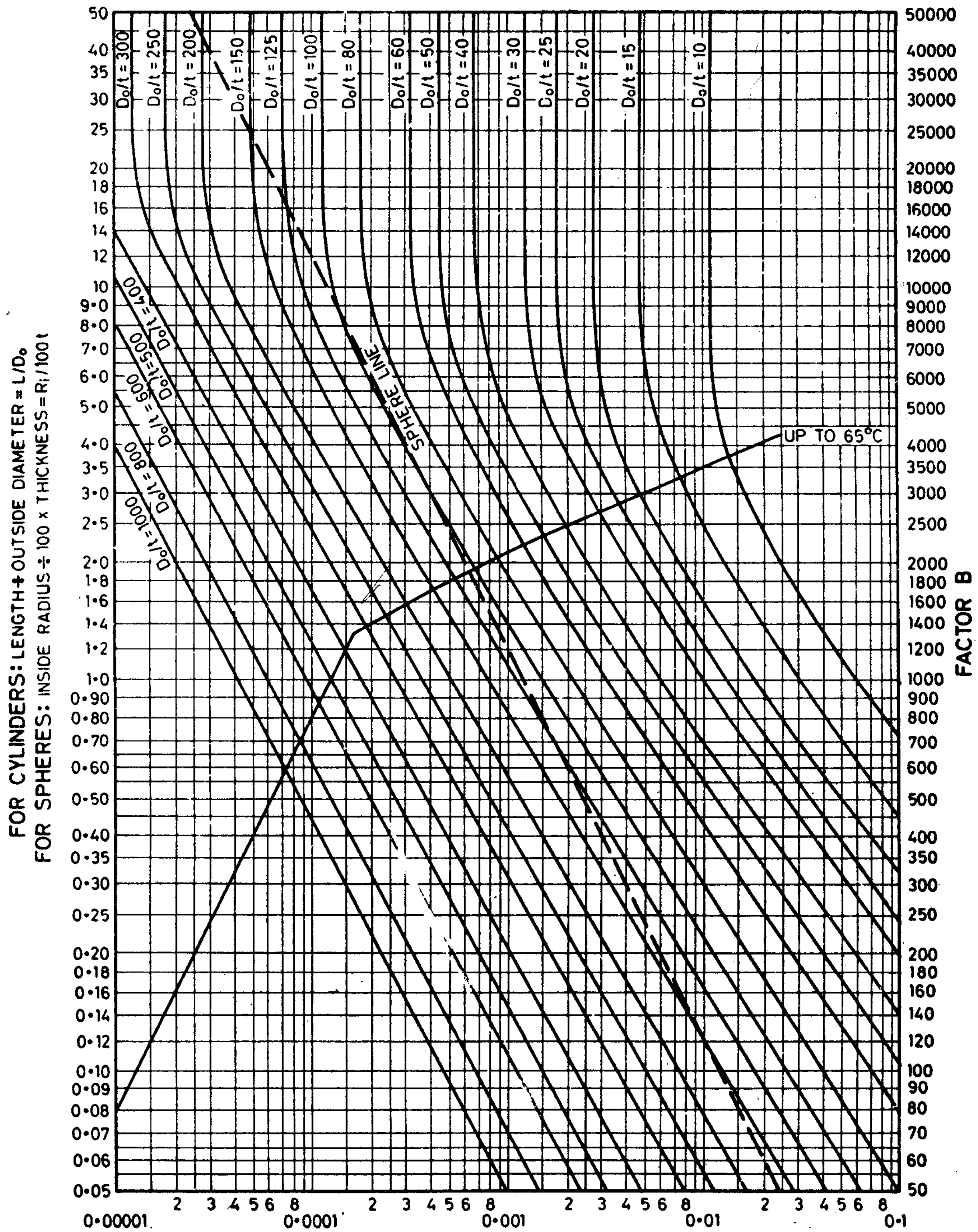


FIG. F.11 CHARTS FOR DETERMINING SHELL THICKNESSES OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE, COPPER (*see* IS : 1972-1961)

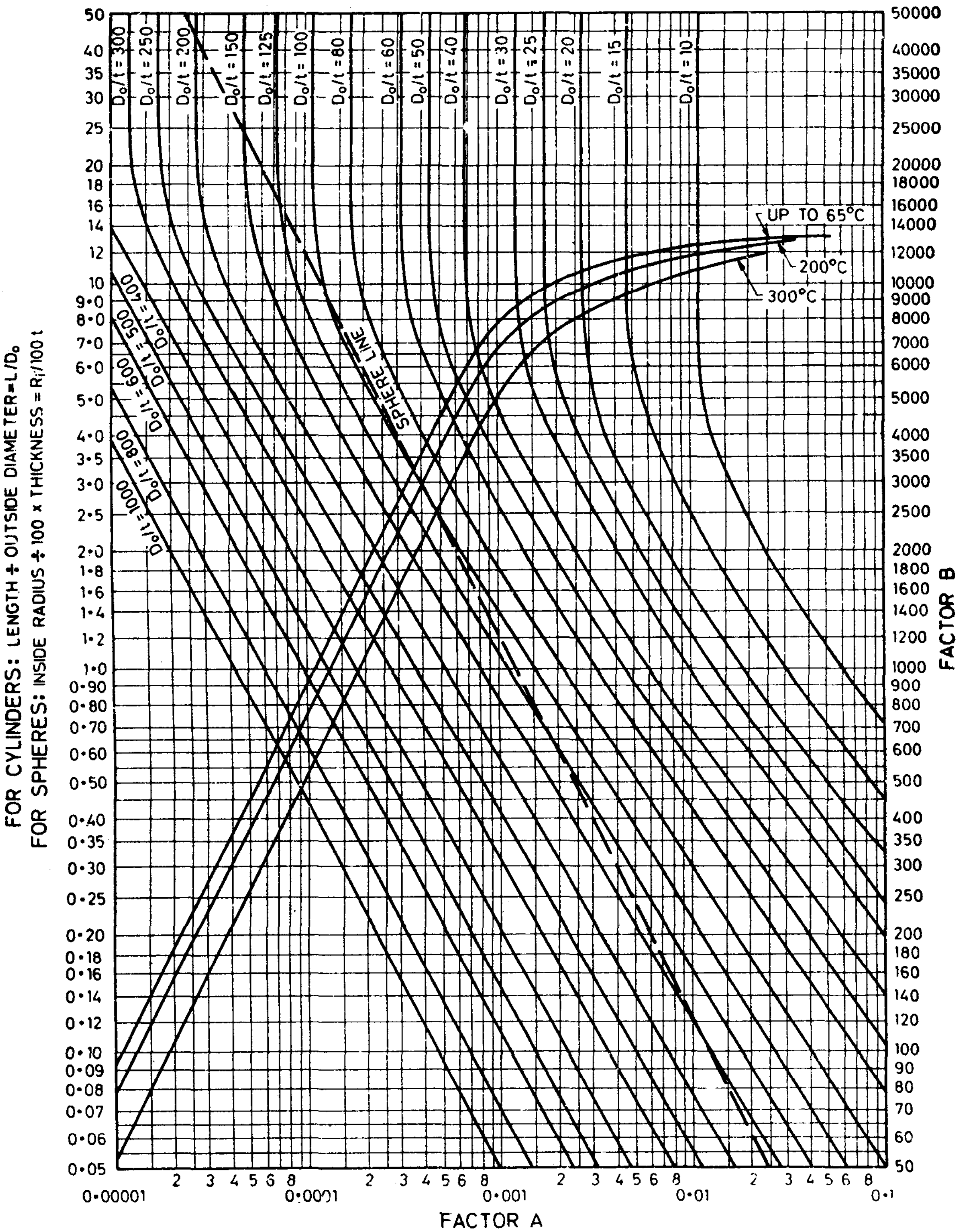


FIG. F.12 CHARTS FOR DETERMINING SHELL THICKNESSES OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE, ALUMINIUM BRONZE (*see* GRADE ISABZT—IS : 1545-1960)

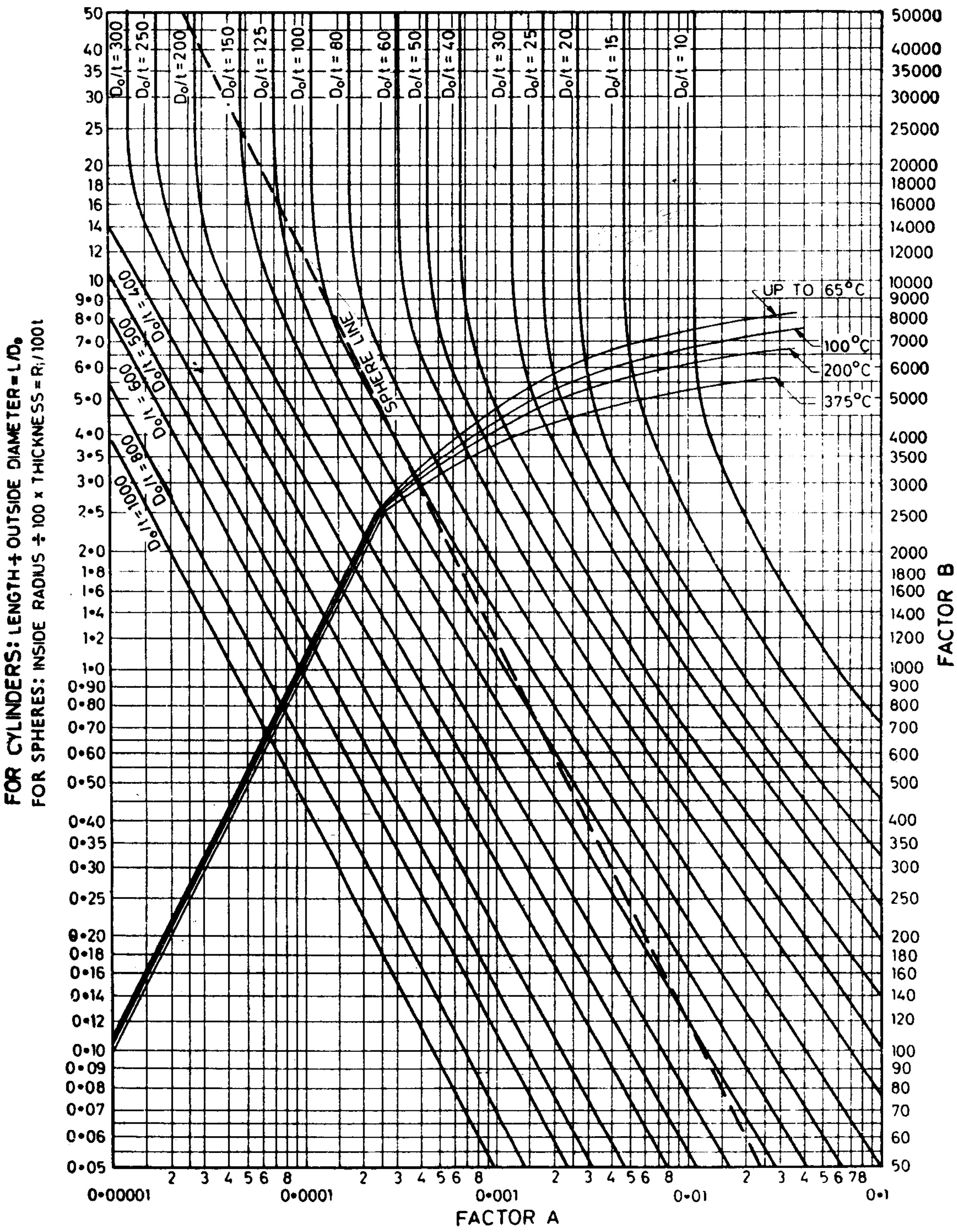


FIG. F.13 CHARTS FOR DETERMINING SHELL THICKNESSES OF CYLINDRICAL AND SPHERICAL VESSELS UNDER EXTERNAL PRESSURE, 70-30 COPPER NICKEL ALLOY (*see* GRADE CuNi31Mn1 Fe OF IS : 2371-1963)

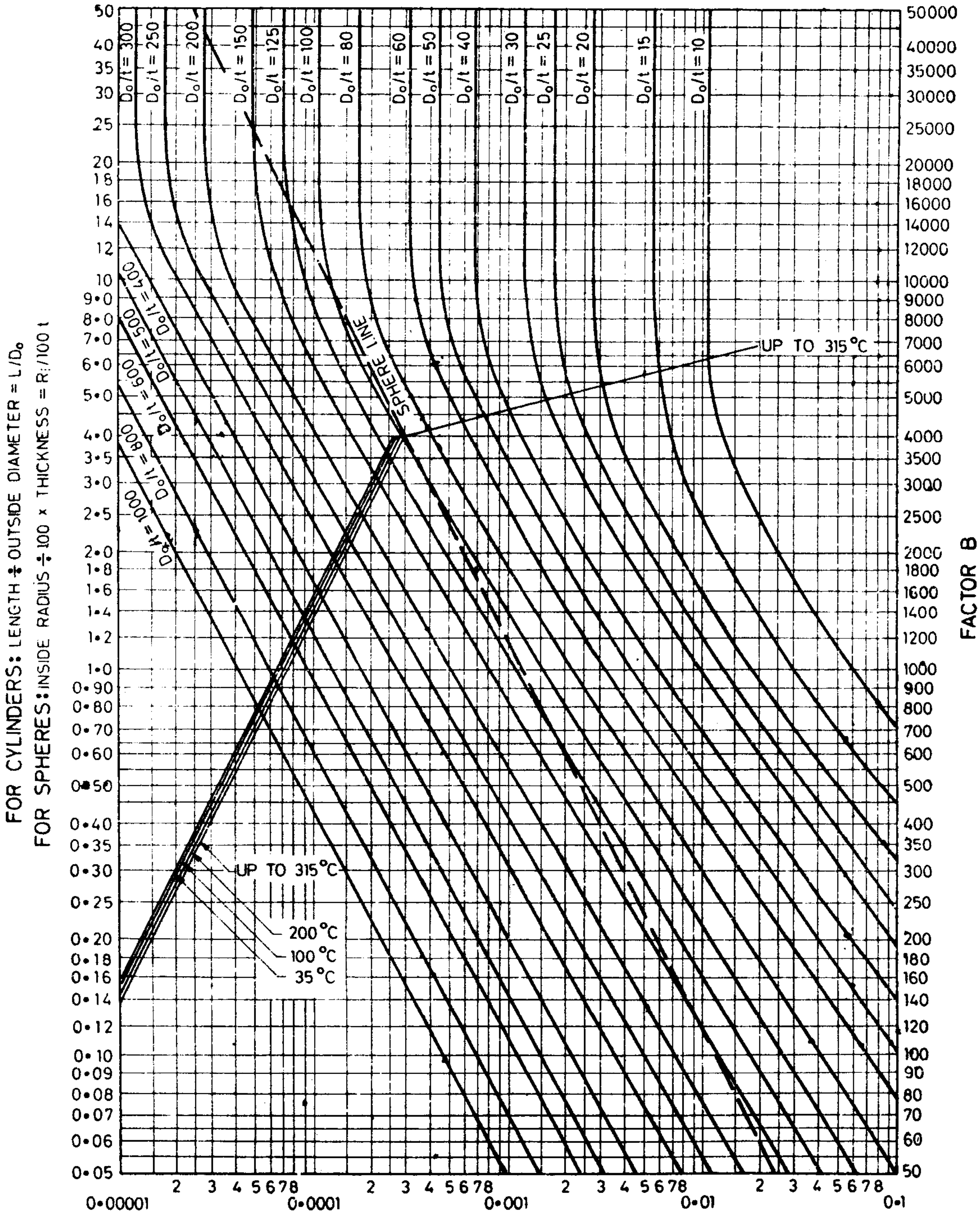


Fig. F.14 Charts for Determining Shell Thicknesses of Cylindrical and Spherical Vessels Under External Pressure, Nickel

APPENDIX G

(*Clause* 6.2.1.1)

TYPICAL DESIGN OF WELDED CONNECTIONS

G-0. GENERAL

G-0.1 The recommended connections are applicable for carbon and low alloy steel vessels.

G-0.2 It is not to be understood that this appendix is mandatory or restricts development in any way, but rather exemplifies sound and commonly accepted practice. That is to say, a number of connections have been excluded which, whilst perfectly sound, are for various reasons, restricted in their use. Furthermore future desirability is appreciated of introducing amendments and additions to reflect improvement in welding procedures, techniques and materials, as they develop.

G-0.3 In selecting the appropriate detail from the several alternatives shown for each type of connection, consideration shall be given to the service condition under which it will be required to function.

G-0.4 Weld groove dimensions and other details (for example, bevel, angles, root faces, root radii and gaps) are not included. However, it should be understood that in boiler work easy access for the deposition of sound weld metal at the root is particularly important in single *J* and single bevel welds and that these welds should be proportioned so as to provide such access.

G-0.5 It is to be noted for boilers and pressure vessels subject to internal corrosion, only connections that are suitable for applying a corrosion allowance should be used. Certain types, such as those incorporating internal attachment by fillet welds only do not lend themselves to this and should be discouraged for use in corrosive duties.

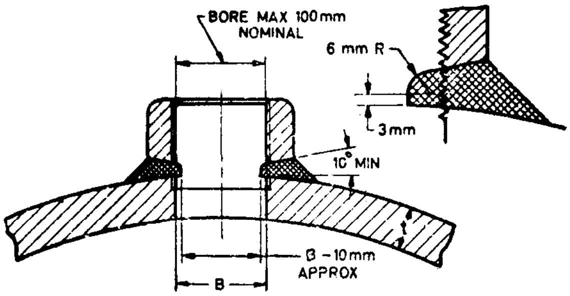
G-1. TYPICAL CONNECTIONS

G-1.1 The following types of connections are covered:

a) Typical designs (general), and

b) Welding of pipe connections.

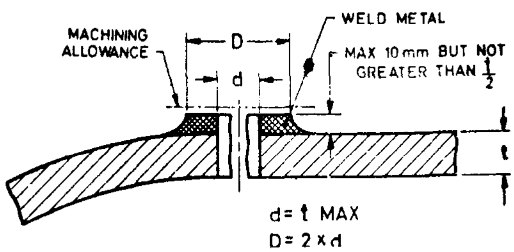
G-1.2 Typical Designs (General) — Notes referred to in the figures given in this appendix may be found at near the end of the appendix.



a) Recommended when no crevice is permitted between socket and wall of vessel. Drill and tap after welding.

b) Screwed connections should not exceed ISP thread size 1½ (*see* IS : 554-1964).

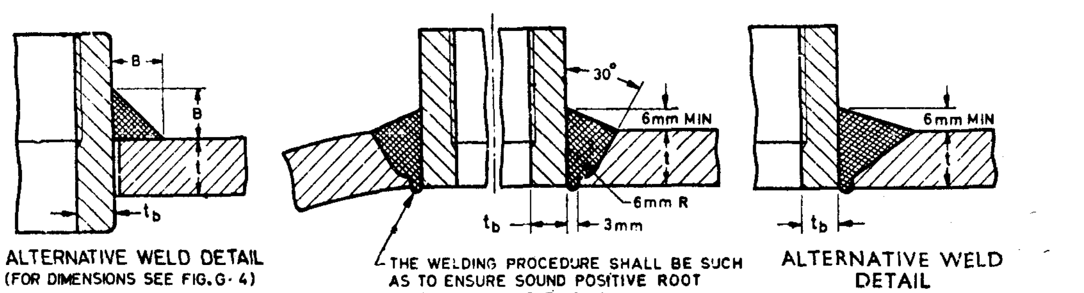
FIG. G.1 SCREWED CONNECTIONS



a) Total thickness of shell plate plus weld should be adequate for number of threads required.

b) Screwed connections should not exceed thread size 1½ (*see* IS : 554-1964).

FIG. G.2 SCREWED CONNECTIONS

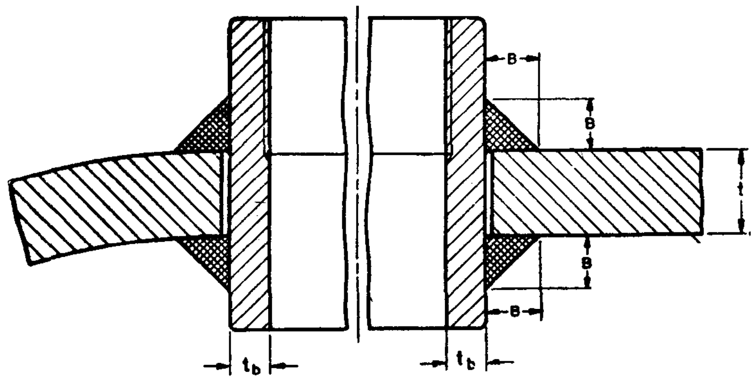


a) If the shell thickness *t* exceeds approx 15 mm, preference should be given to joint shown in Fig. G.1.

b) Not recommended where inside of vessel is accessible for welding.

c) Screwed connections should not exceed ISP thread size 1½ [*see* IS : 554-1964 ' Dimensions for pipe threads for gas list tubes and pressure tight screwed fittings (*revised*) '].

FIG. G.3 WELDED SOCKETS (SCREWED)



t_b mm	3	5	6	8	10	11	13	14	16	18	19
B mm	6	8	10	13	14	15	17	20	21	23	27

a) If the required fillet size exceeds about 15 mm, then details given in Fig. G.5 should be used.

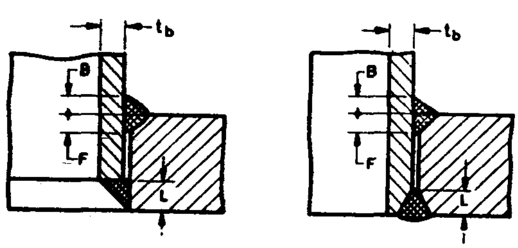
b) The branch should be a loose fit in the hole but the gap at any point should not exceed 3 mm or $t_b/2$ whichever is less.

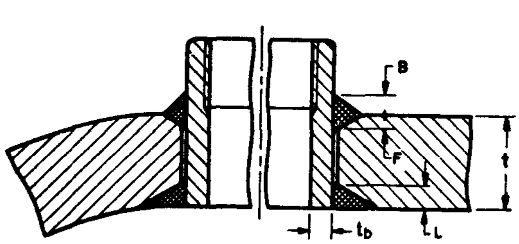
c) The intent of the limitation in the size of the fillet weld is to maintain the stress field induced by welding within reasonable limits.

d) Screwed connections should not exceed ISP thread size 1½ (*see* IS : 554-1964).

e) t = Thickness of socket (t_b) or shell (t) whichever is smaller.

FIG. G.4 WELDED SOCKETS (SCREWED)





Weld size $B + F = 1{\cdot}5\ t_b$ *Min* or $1{\cdot}5\ t$ *Min* whichever is less.

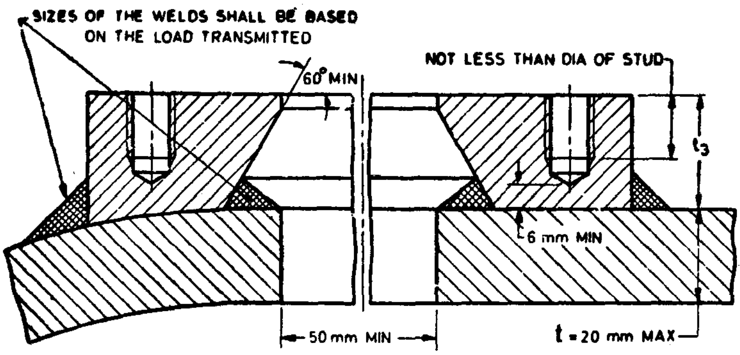
B should not exceed 15 mm nor be less than $t_b/2$.

$L = t_b$.

a) The branch should be a loose fit in the hole but the gap at any point should not exceed 3 mm or $t_b/2$ whichever is less.

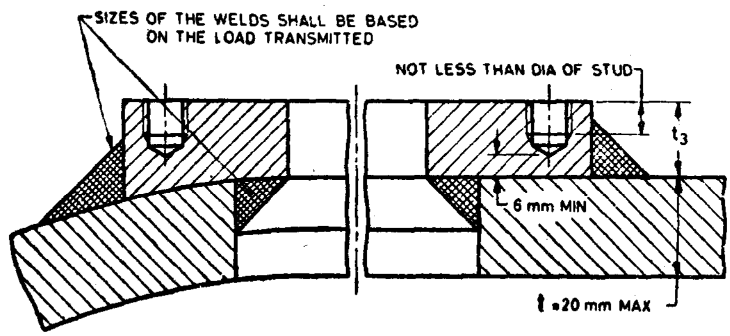
b) Its use when thermal gradient may cause overstress in welds to be avoided.

FIG. G.5 WELDED SOCKETS (SCREWED)



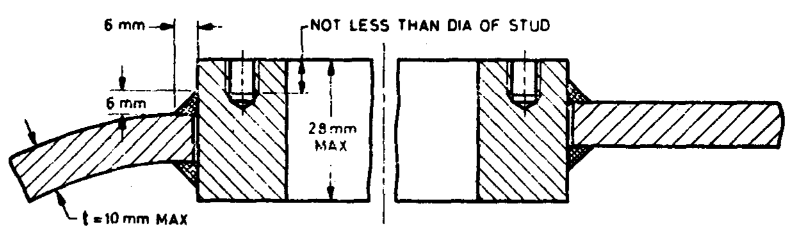
a) Its use when thermal gradient may cause overstress in welds to be avoided.
b) Recommended for light duty vessels.

FIG. G.6 WELDED SEATINGS



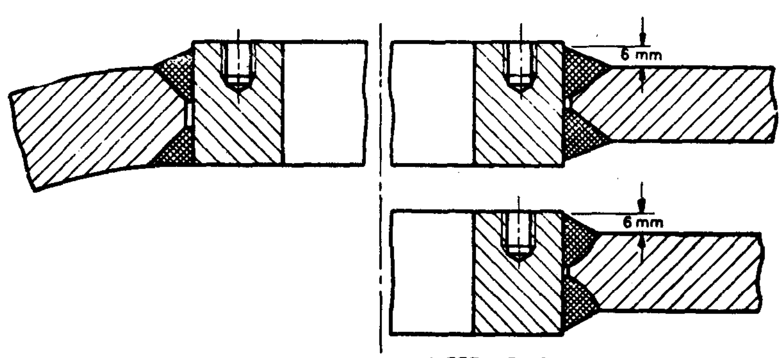
a) Its use when thermal gradient may cause overstress in welds to be avoided.
b) Recommended for light duty vessels.

FIG. G.7 WELDED SEATINGS



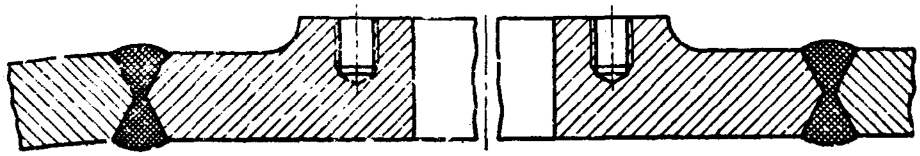
a) This detail is only recommended if vessel is not subject to pulsating loads and the shell thickness does not exceed 10 mm maximum.
b) Its use when thermal gradient may cause overstress in welds to be avoided. Recommended for light duty vessels. The weld sizes are minimum.

FIG. G.8 WELDED SEATINGS



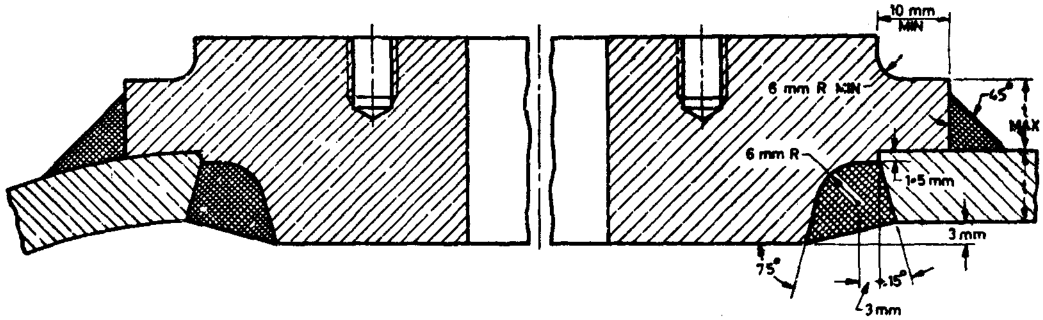
Special precautions should be taken to minimize the stresses induced by welding.

FIG. G.9 WELDED SEATINGS



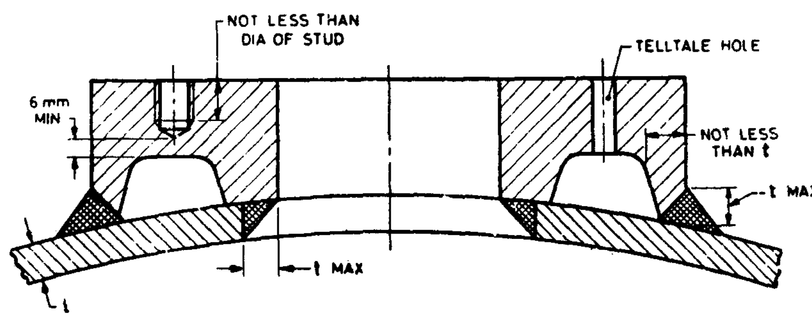
Special precautions should be taken to minimize the stresses induced by welding.

FIG. G.10 WELDED SEATINGS



Weld dimensions are minimum.

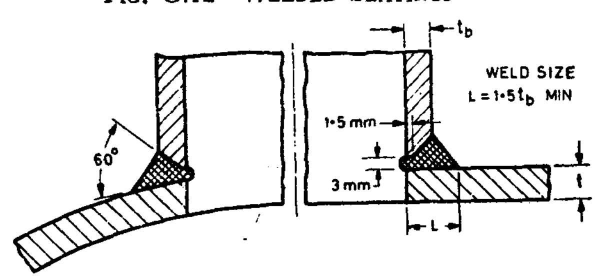
FIG. G.11 WELDED SEATINGS



(Recommended for light duty vessels)

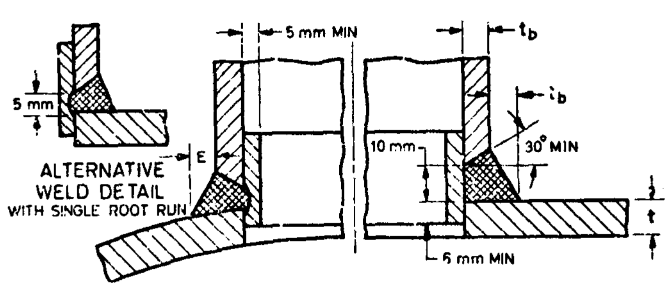
NOTE — The pad is not to be taken into account in calculating the reinforcement required.

FIG. G.12 WELDED SEATINGS



See Notes 3, 4 and 5 on page 223.

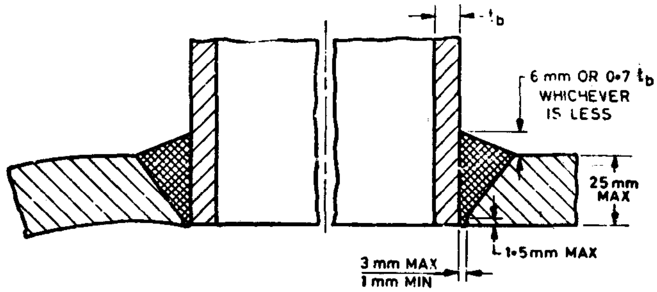
FIG. G.13 WELDED BRANCHES



Backing ring removed on completion of welding if required.

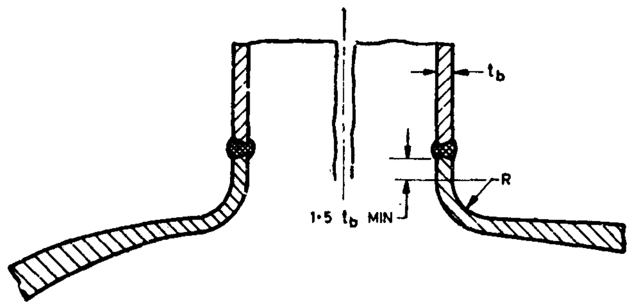
t_b *Min* mm	4	5	6	8	10	11	13	14	16	18	19
E *Min* mm	2	4	4	5	5	6	6	8	8	10	10

FIG. G.14 WELDED BRANCHES



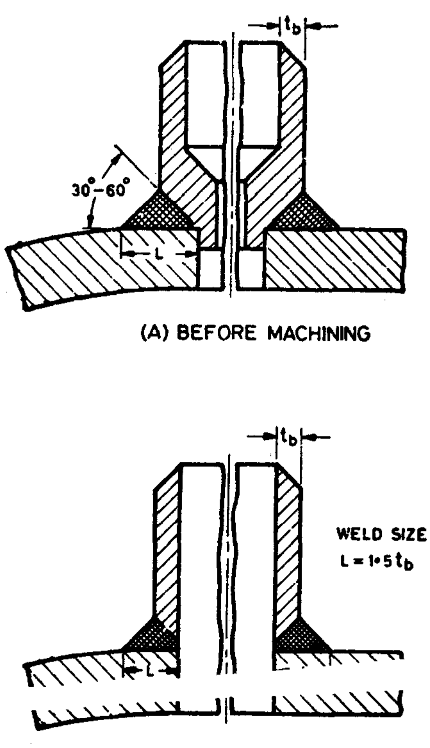
See Notes 1, 2, 3, 5 and 6 on page 223.

FIG. G.15 WELDED BRANCH



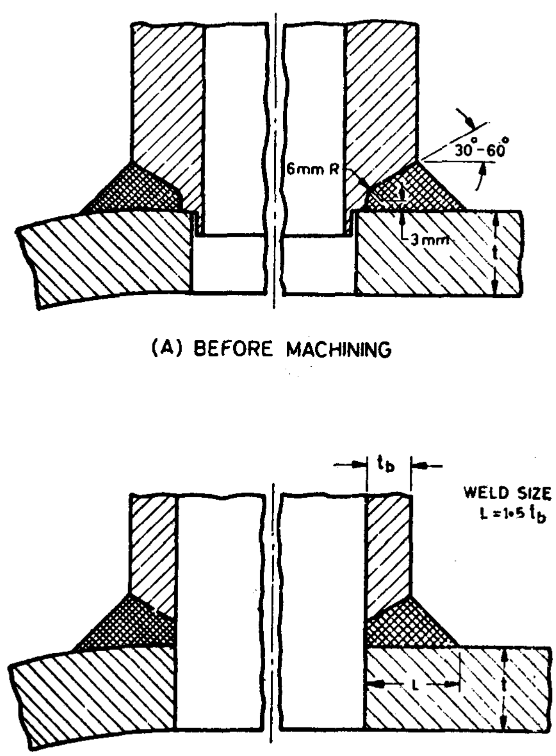
See Notes 5 and 6 on page 223.

FIG. G.16 WELDED BRANCH FOR FLANGED NECK



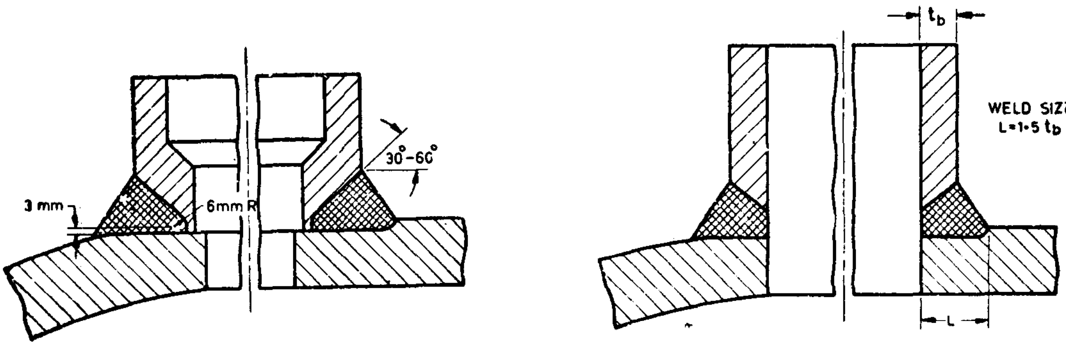
See Notes 4 and 7 on page 223.

FIG. G.17 WELDED BRANCH



See Notes 4 and 7 on page 223.

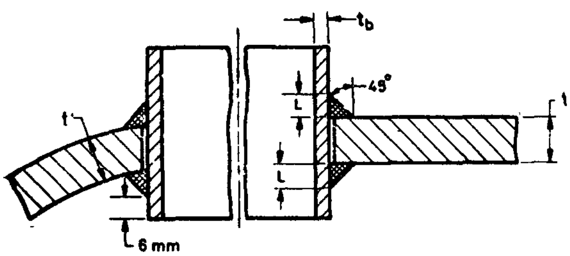
FIG. G.18 WELDED BRANCH



(A) BEFORE MACHINING (B) AFTER MACHINING

See Notes 4 and 5 on page 223.

FIG. G.19 WELDED BRANCH

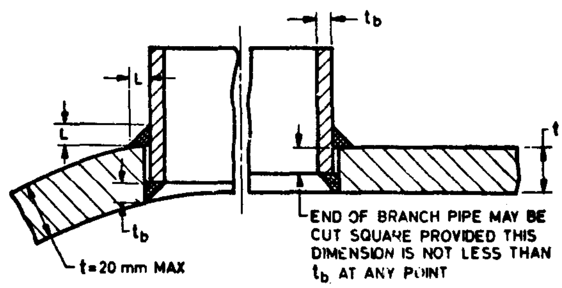


a) For light duty vessels, dimension L is same as dimension B in Fig. G.4.

b) Its use when thermal gradient may cause overstress in welds to be avoided.

c) *See* Notes 1, 2, 12 and 15 on page 223.

FIG. G.20 WELDED BRANCH

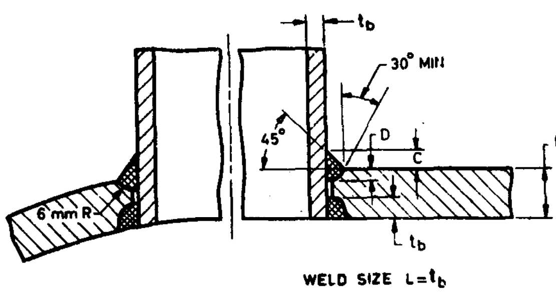


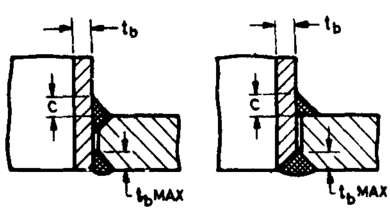
a) For light duty vessels, dimension L is same as dimension B in Fig. G.4.

b) Its use when thermal gradient may cause overstress in welds to be avoided.

c) *See* Notes 1, 2, 12 and 15 on page 223.

FIG. G.21 WELDED BRANCH





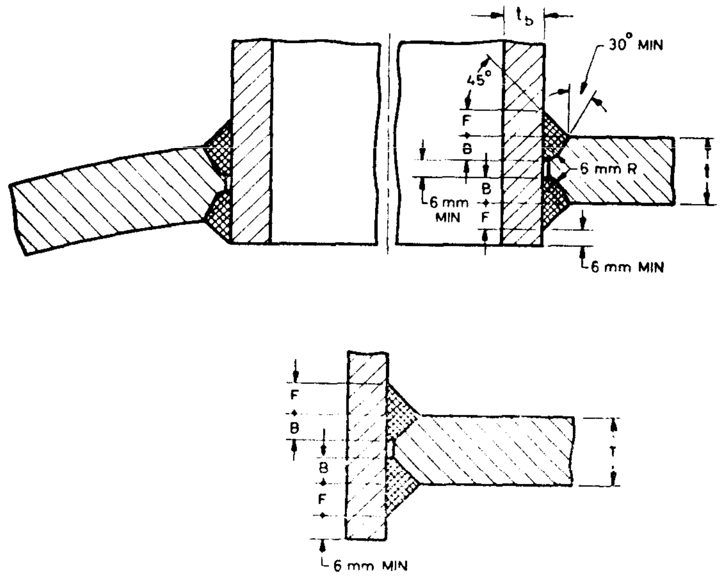
ALTERNATIVE WELD DETAILS

Its use when thermal gradient may cause overstress in weld to be avoided.

t_b mm	14	16	17·5	19	22	25	29	32	35	38
C mm	15	15	19	19	21	25	25	25	25	25
D mm	7	8	8	10	11	12	17	21	27	32

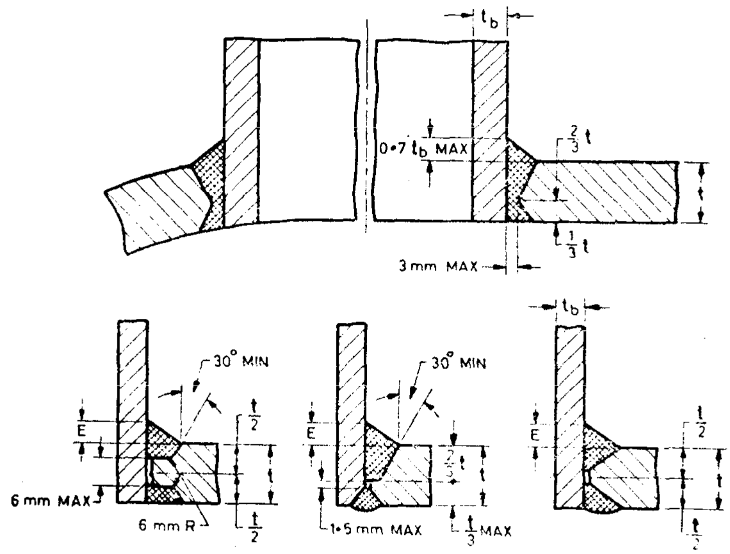
(Weld dimensions are minimum)

FIG. G.22 WELDED BRANCH



See Notes 1, 2, 11 and 16 on page 223.

FIG. G.23 WELDED BRANCH

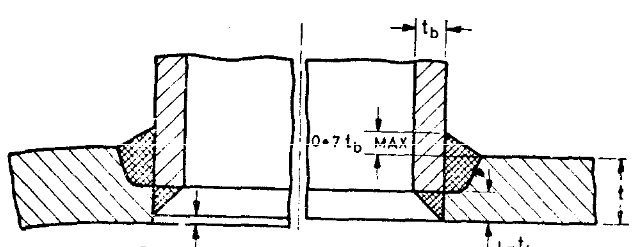


E = 6 mm OR 0·7 t_b WHICHEVER IS LESS

ALTERNATIVE WELD DETAILS

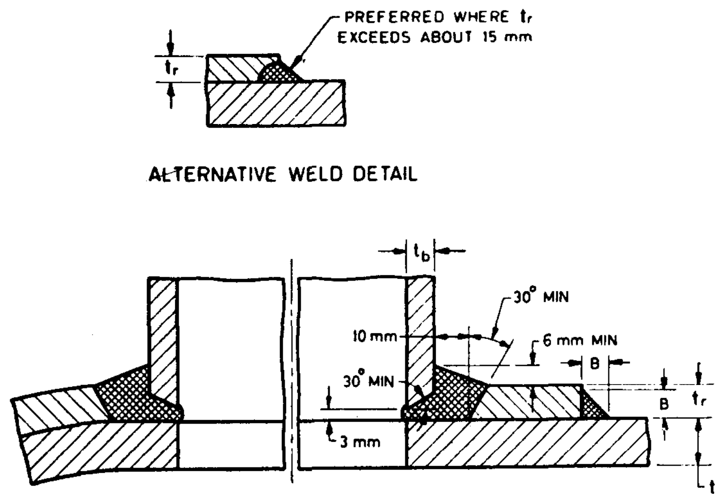
See Notes 1, 2 and 3 on page 223.

FIG. G.24 WELDED BRANCH



See Notes 1, 2 and 3 on page 223.

FIG. G.25 WELDED BRANCH



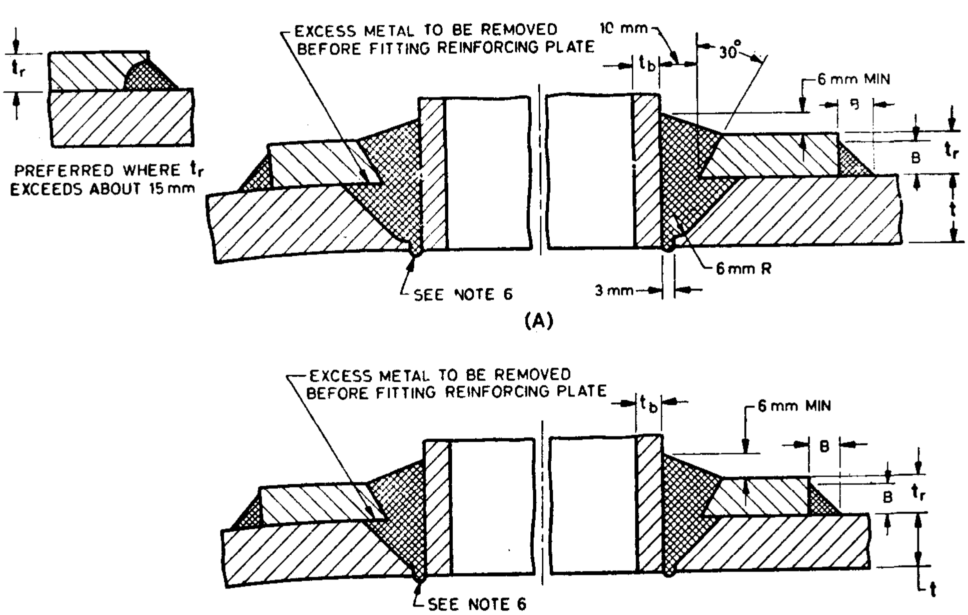
a) The branch to shell joint with backing ring as shown in Fig. G.3.

b) When thermal gradient may cause overstress in the welds connecting the reinforcement, its use should be avoided.

c) Fillet weld size $B = 0{\cdot}7\ t_r$ or $0{\cdot}7\ t$ whichever is less with a maximum of 15 mm.

d) *See* Notes 1, 4 and 5 on page 223.

FIG. G.26 WELDED BRANCH

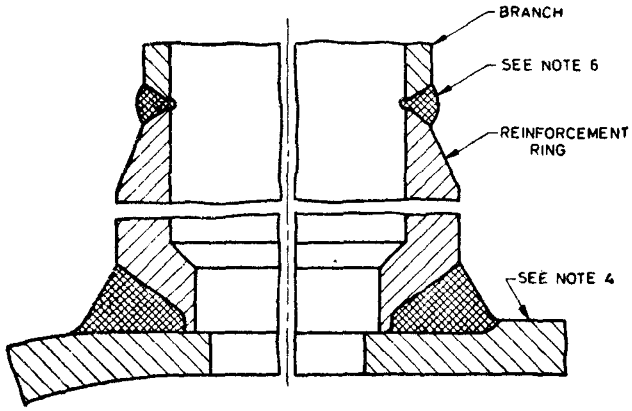


a) When thermal gradient may cause overstress in the welds connecting the reinforcement, its use should be avoided.

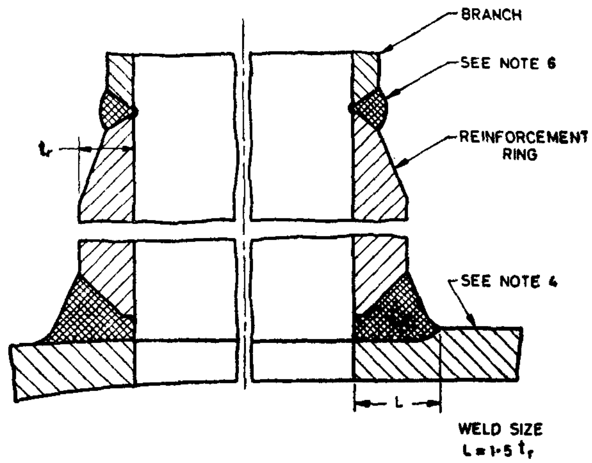
b) Fillet weld size $B = 0{\cdot}7\ t_r$ or $0{\cdot}7\ t$ whichever is less with a maximum of 15 mm.

c) *See* Notes 1, 2, 3 and 5 on page 223.

FIG. G.27 WELDED BRANCHES



(A) BEFORE MACHINING



(B) AFTER MACHINING

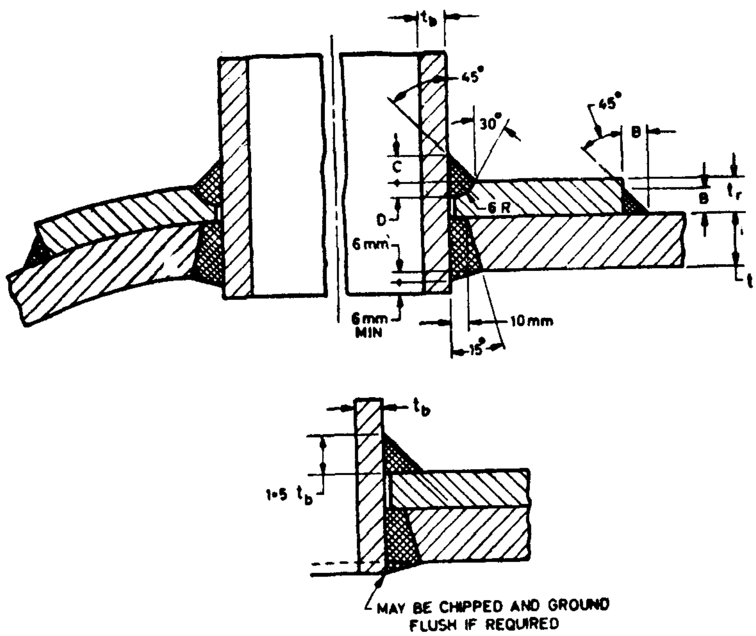
a) Before machining connection may also be used when there is accessibility for welding inside the shell.

b) After machining connection is limited to conditions where adequate compensation may be obtained with the type of reinforcing ring shown.

c) For alternative butt weld preparations between reinforcement ring and branch, *see* Fig. G.43, G.76 and G.77.

d) *See* Notes on page 223.

FIG. G.28 WELDED BRANCHES



a) When thermal gradient may cause overstress in the welds connecting the reinforcement, its use may be avoided.

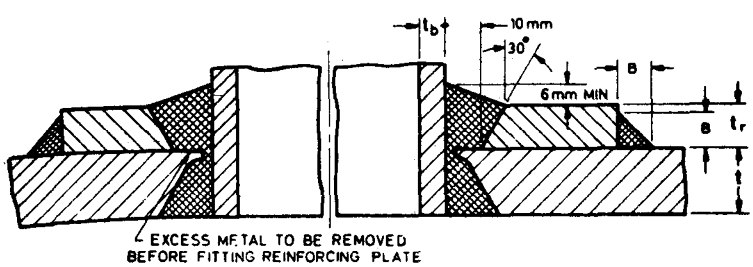
b) Values of C and D as given in Fig. G.22.

c) Fillet weld size $B = 0{\cdot}7\ t_r$ or $0{\cdot}7\ t$ whichever is less with a maximum of 15 mm.

d) Preferred where t_r exceeds about 15 mm.

e) *See* Notes 1, 2, 3, 8 and 10 on page 223.

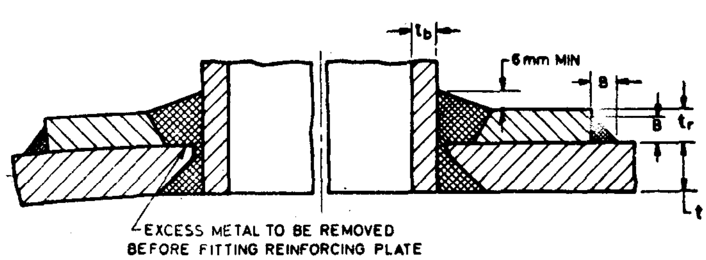
FIG. G.29 WELDED BRANCH



a) Fillet weld size $B = 0{\cdot}7\ t_r$ or $0{\cdot}7$ whichever is less with a maximum of 15 mm.

b) *See* Notes 1, 2, 3 and 8 on page 223.

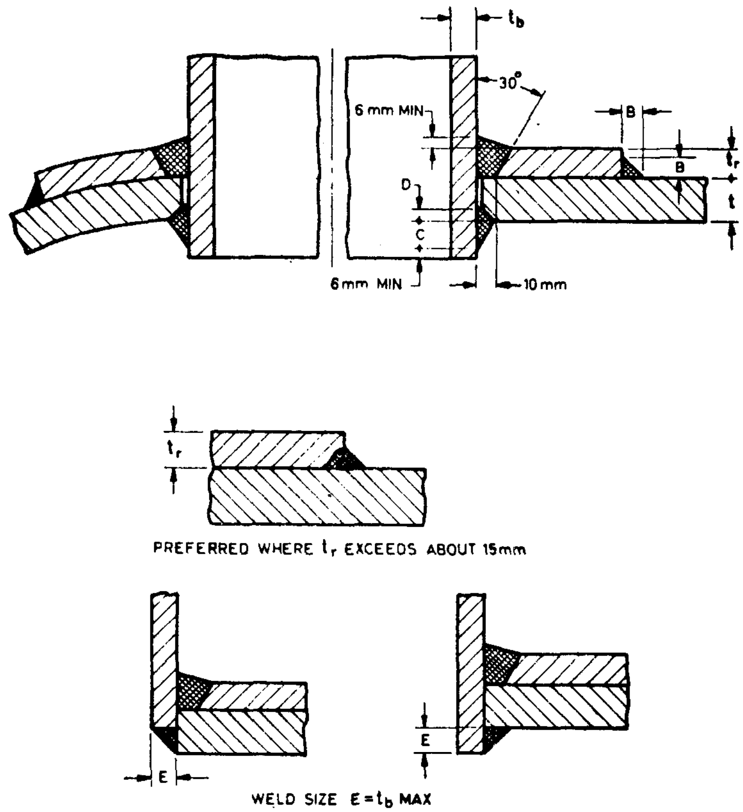
FIG. G.30 WELDED BRANCH



a) Fillet weld size $B = 0{\cdot}7\ t_r$ or $0{\cdot}7\ t$ whichever is less with a maximum of 15 mm.

b) *See* Notes 1, 2, 3 and 8 on page 223.

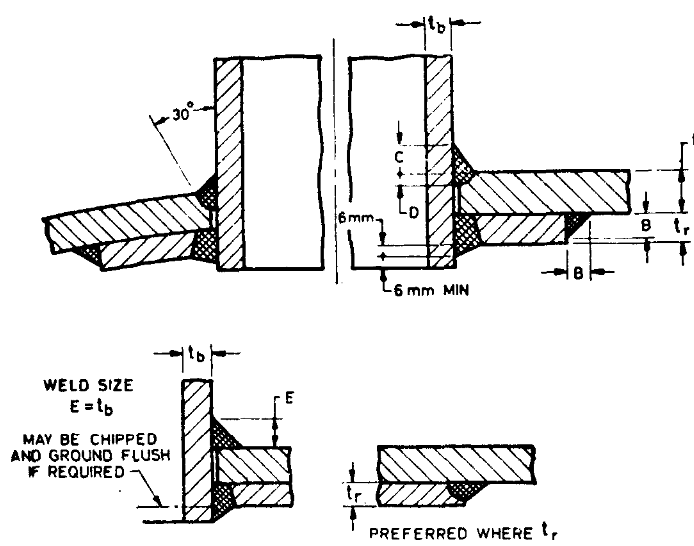
FIG. G.31 WELDED BRANCH



ALTERNATIVE WELD DETAILS

a) Fillet weld size $B = 0{\cdot}7\ t_r$ or $0{\cdot}7\ t$ whichever is less with a maximum of 15 mm.
b) Values of dimensions C and D as in Fig. G.22.
c) *See* Notes 1, 2, 3, 8 and 10 on page 223.

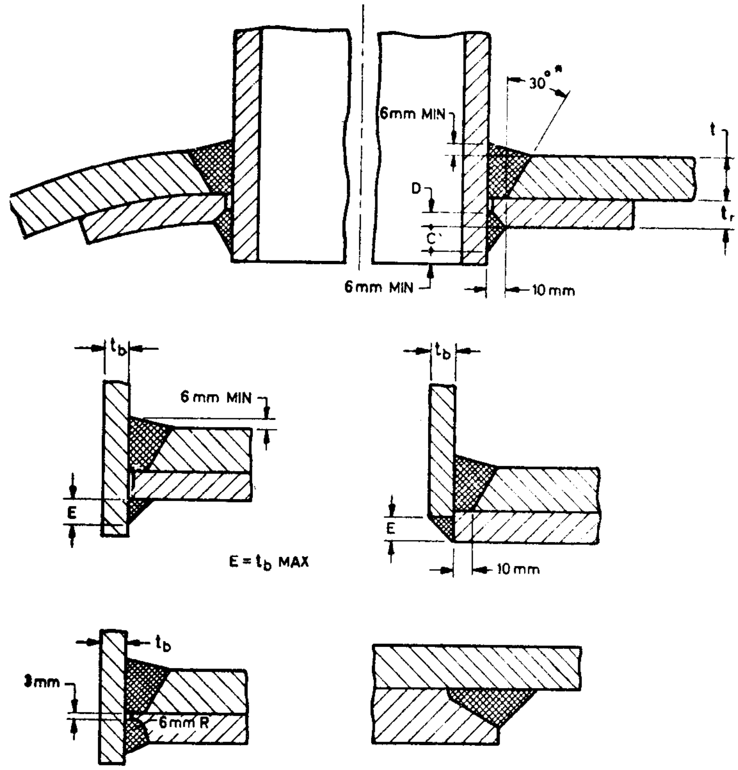
Fig. G.32 Welded Branch



ALTERNATIVE WELD DETAILS

a) In the range t_b = 14 to 20 mm the choice between a fillet or a fillet plus groove weld should depend on relative cost.
b) Weld dimensions are minimum.
c) When thermal gradient may cause overstress in the welds connecting the reinforcement, its use may be avoided.
d) Values C and D as given in Fig. G.22.
e) Fillet weld size $B = 0{\cdot}7\ t_r$ or $0{\cdot}7\ t$ whichever is less with a maximum of 15 mm.
f) *See* Notes 1, 2 and 11 on page 223.

Fig. G.33 Welded Branch



ALTERNATIVE WELD DETAILS

*This angle to be increased where proximity of flange restricts access.

a) Compensating plate may be fitted to inside of vessel if desired. Arrangement of welding groove may be reversed if desired. In the range t_b = 14 to 20 mm, the choice between a fillet or a fillet plus groove weld should depend on relative cost. Weld dimensions are minimum.

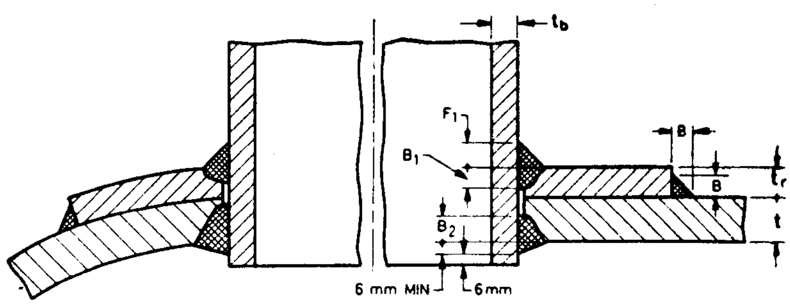
b) When thermal gradient may cause overstress in the welds connecting the reinforcement, its use may be avoided.

c) The values of C and D are the same as given in Fig. G.22.

d) Fillet weld size $B = 0{\cdot}7\ t_r$ or $0{\cdot}7\ t$ whichever is less with a maximum of 15 mm.

e) *See* Notes 1, 2, 11 and 15 on page 223.

FIG. G.34 WELDED BRANCH



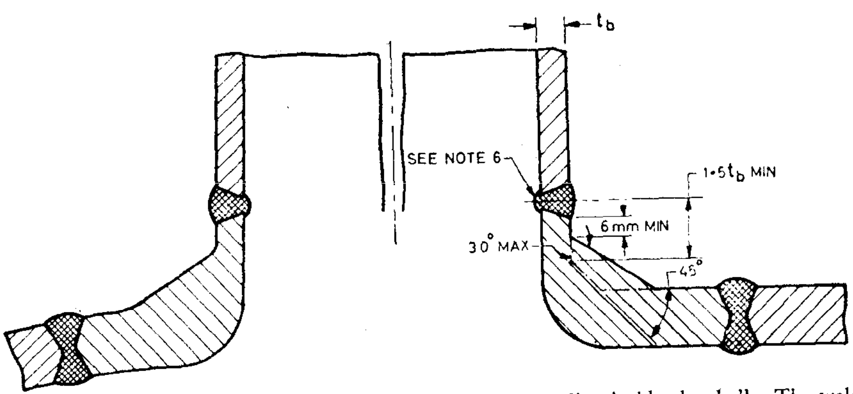
a) When thermal gradient may cause overstress in the welds connecting the reinforcement, its use may be avoided.

b) Fillet weld size $B = 0{\cdot}7\ t_r$ or $0{\cdot}7\ t$ whichever is less with a maximum of 15 mm.

c) *See* Notes 1, 2 and 13 on page 223.

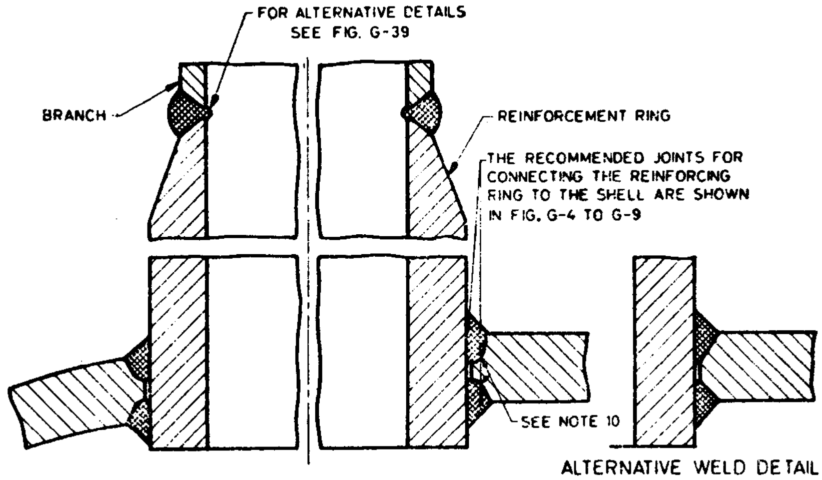
FIG. G.35 WELDED BRANCH

FIG. G-36 Under Consideration



This connection may also be used when there is no access for welding inside the shell. The welding procedure should be such as to ensure sound positive root penetration.

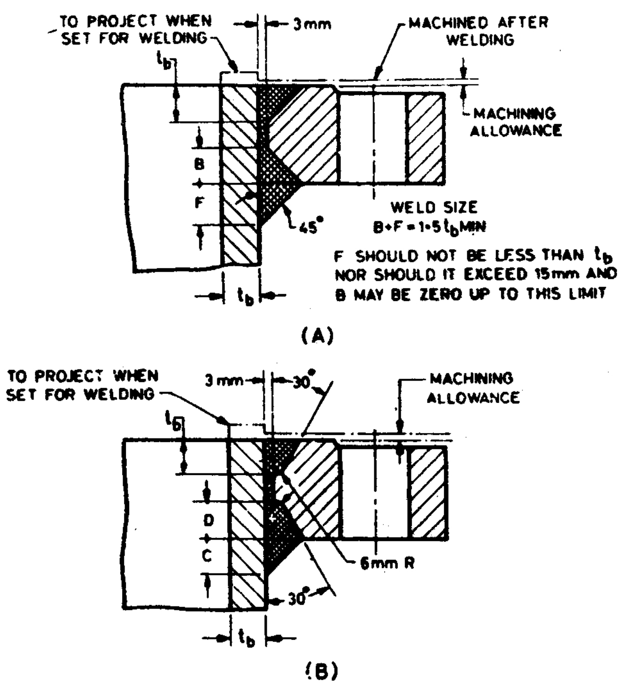
FIG. G.37 WELDED BRANCH WITH NECK PIECE



a) The use of this connection is limited to conditions where adequate compensation may be obtained with the type of reinforcement shown.

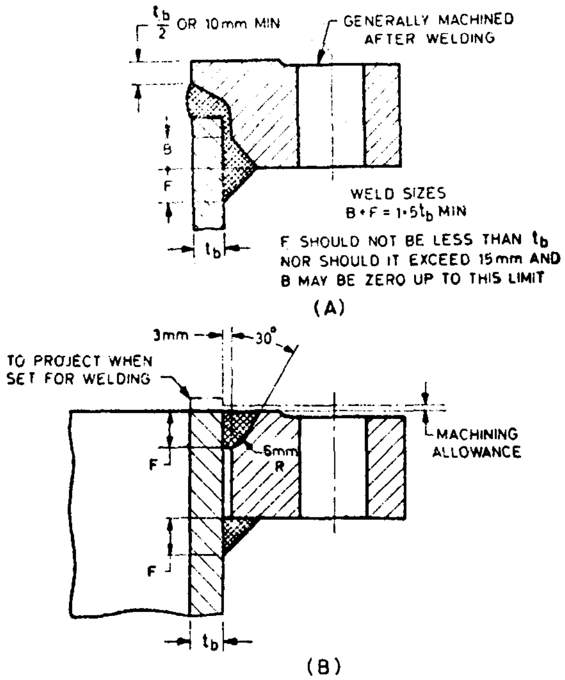
b) *See* Notes on page 223.

FIG. G.38 WELDED BRANCH (REINFORCED)



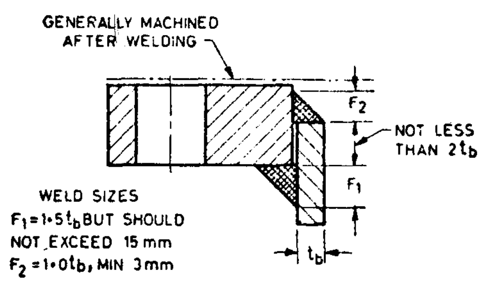
Dimensions C and D as in Fig. G.22.

FIG. G.39 WELDED FLANGES



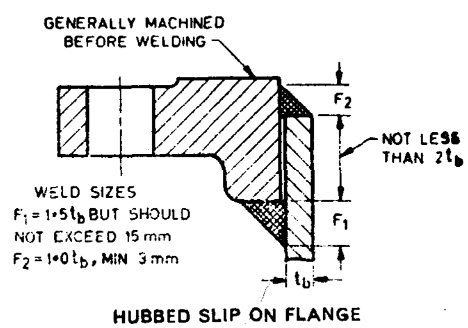
To be avoided when thermal gradient may cause overstress in welds and/or fatigue when conditions exist.

Fig. G.40 Welded Flanges



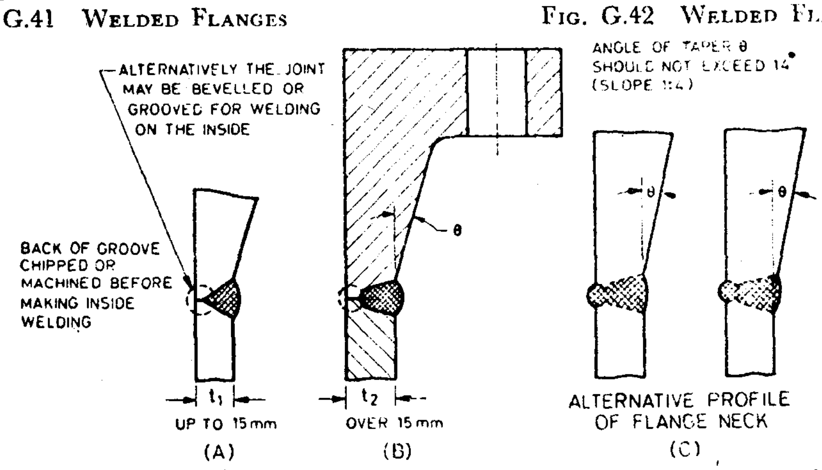
a) To be avoided when thermal gradient may cause overstress in welds and/or fatigue when conditions exist.
b) In certain cases a smaller limitation of weld size F_1 equal to 1·0 t_b is preferred.

Fig. G.41 Welded Flanges



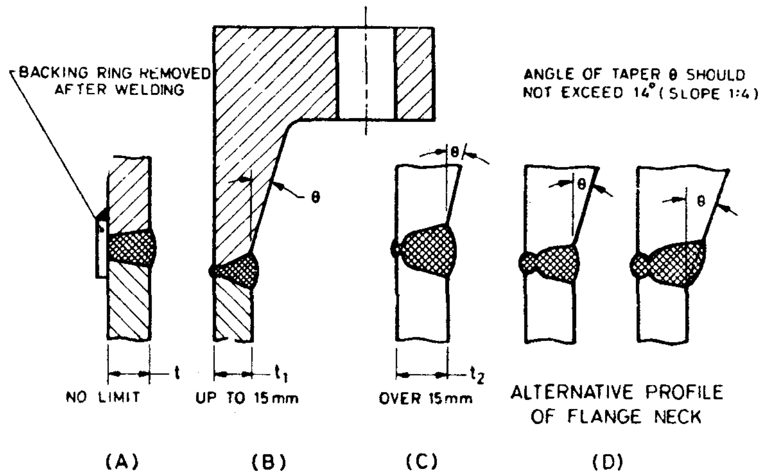
In certain cases a smaller limitation of weld size F_1 equal to 1·0 t_b is preferred.

Fig. G.42 Welded Flanges



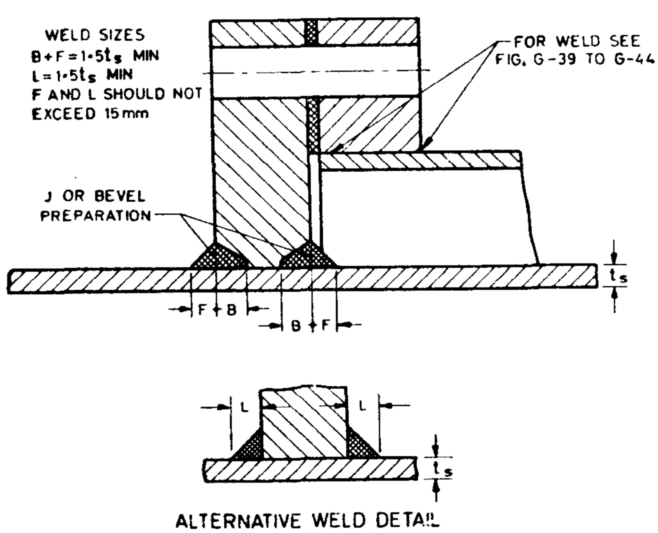
This connection may also be used when there is process for welding from inside. The welding procedure should be such as to ensure sound positive root penetration.

Fig. G.43 Welded Flanges



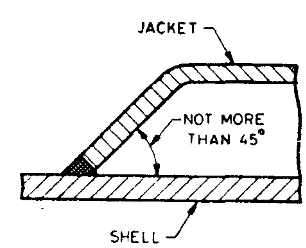
This connection may also be used when there is no access for welding from inside. The welding procedure shall be such as to ensure sound positive root penetration in the butt joint.

FIG. G.44 WELDED FLANGES



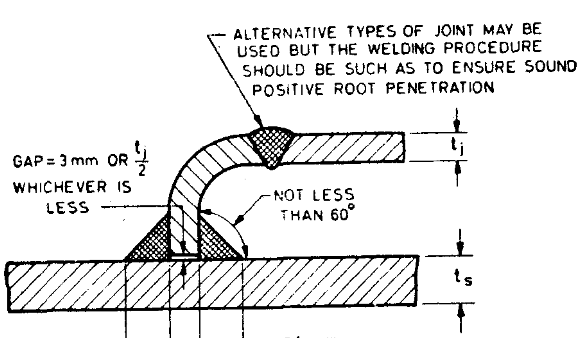
In certain cases limitation in weld size of L equal to $1{\cdot}0\ t_s$ is preferred.

FIG. G.45 JACKETED CONNECTIONS



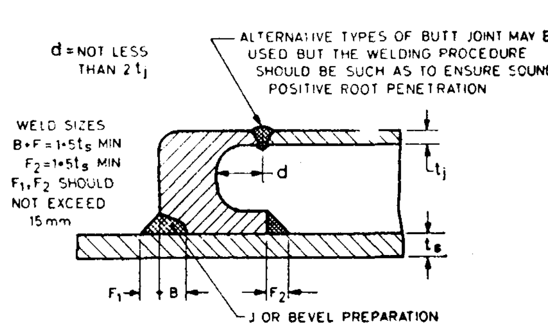
The welding procedure shall be such as to ensure sound positive penetration in the joint.

FIG. G.46 JACKETED CONNECTIONS



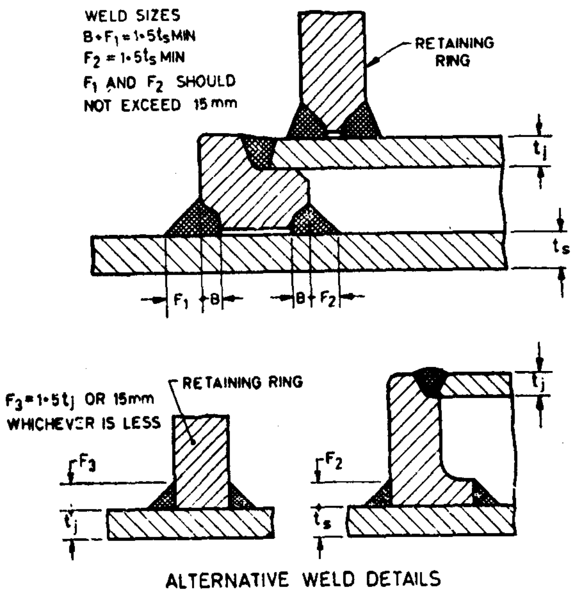
In certain cases a smaller limitation in weld size of F_1 and F_2 equal to $1{\cdot}0\ t_b$ is preferred.

FIG. G.47 JACKETED CONNECTIONS



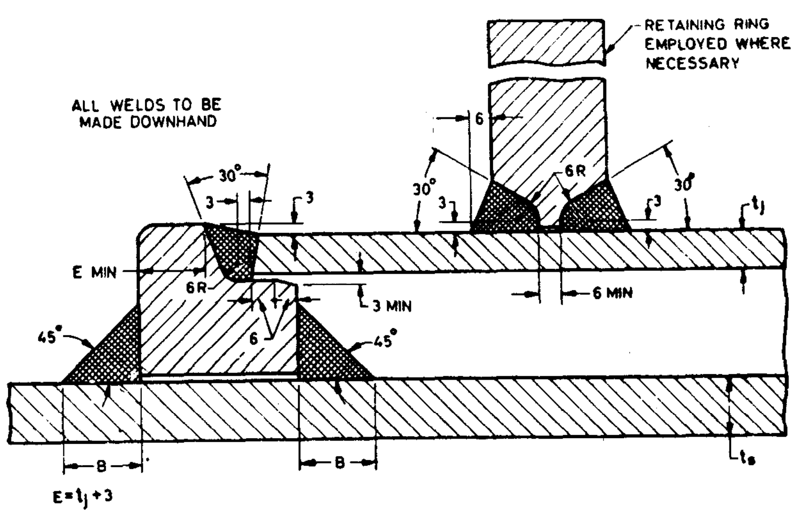
In certain cases a smaller limitation in weld size of F_1 and F_2 equal to $1{\cdot}0\ t_b$ is preferred.

FIG. G.48 JACKETED CONNECTIONS



In certain cases a smaller limitation in weld size of F_1 and F_2 equal to 1·0 t_s is preferred.

FIG. G.49 JACKETED CONNECTIONS

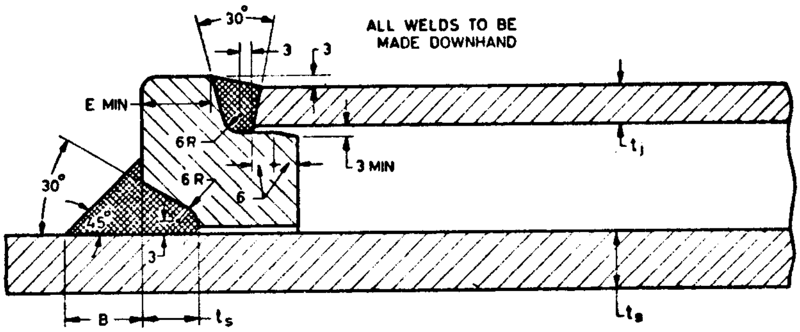


a) Attachment of jacket to vessel having a wall thickness not greater than 20 mm.
b) Weld dimensions are minimum.

t_s	5	6	8	10	11	12	14	15	18	20
B	8	10	12	14	15	17	20	21	24	27

All dimensions in millimetres.

FIG. G.50 JACKETED CONNECTIONS



$E = t_j + 3$

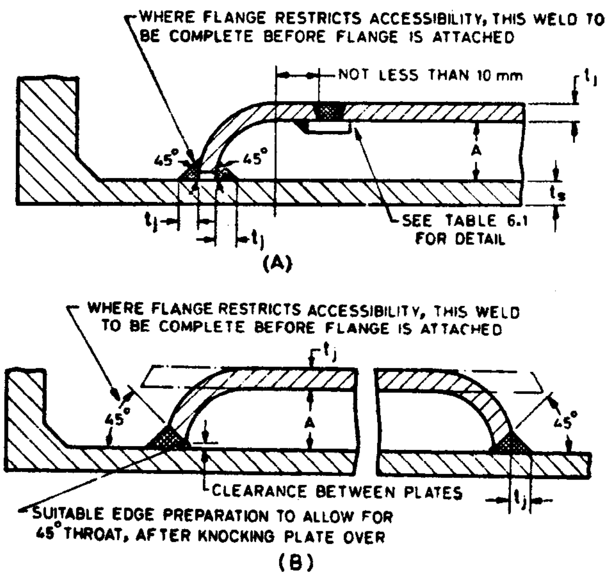
a) Attachment of jacket to vessel having a wall thickness not greater than 20 mm and where there is no access for making a weld inside the jacket space.

b) Weld dimensions are minimum.

t_s	5	6	8	10	11	12	14	15	18	20
B	8	10	12	14	15	17	20	21	24	27

All dimensions in millimetres.

FIG. G.51 JACKETED CONNECTIONS

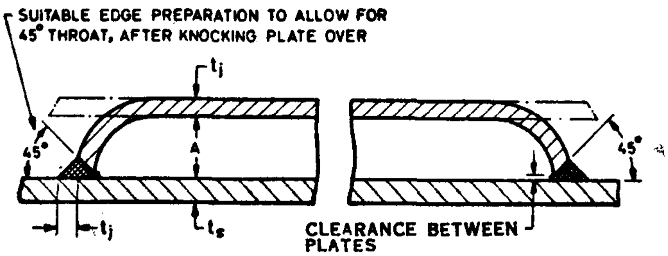


a) Permissible only where both fillet welds are fully accessible for welding.

b) Both ends of jacket attached to cylindrical portion of vessel.

JACKET PLATE THICKNESS t_j mm	JACKET WIDTH A DEPENDING ON DIA OF VESSEL mm
5	31 *Max*
6	31 to 45 *Max*
10	37 to 50 *Max*
12	50

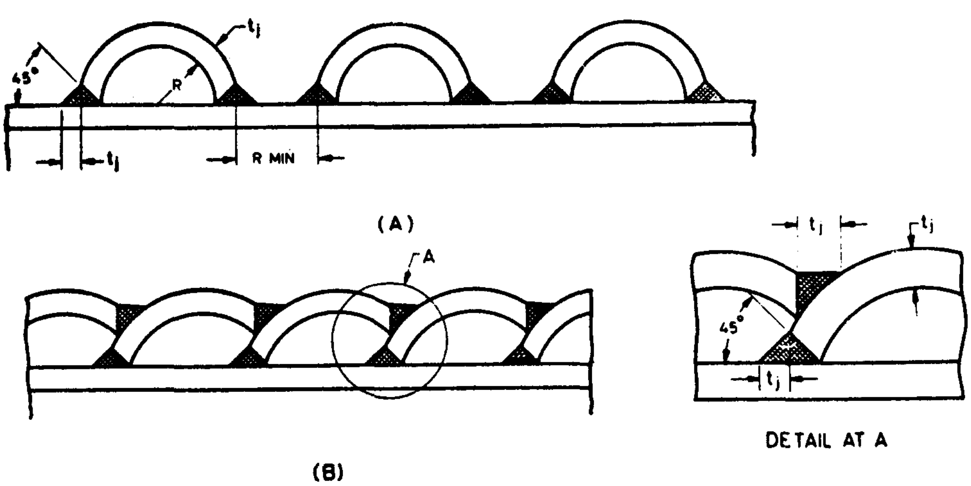
FIG. G.52 JACKETED CONNECTIONS



Both ends of jacket attached to cylindrical portion of vessel.

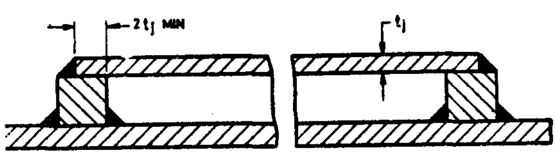
JACKET PLATE THICKNESS t_j mm	JACKET WIDTH *A* DEPENDING ON DIA OF VESSEL mm
5	31 *Max*
6	31 to 45 *Max*
10	37 to 50 *Max*
12	50

FIG. G.53 JACKETED CONNECTIONS



(For light duty vessels only)

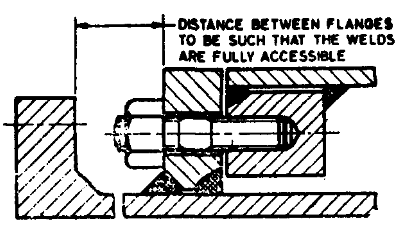
FIG. G.54 JACKETED CONNECTIONS



Both ends of jacket attached to cylindrical portion of vessel.

(For class 3 vessels only)

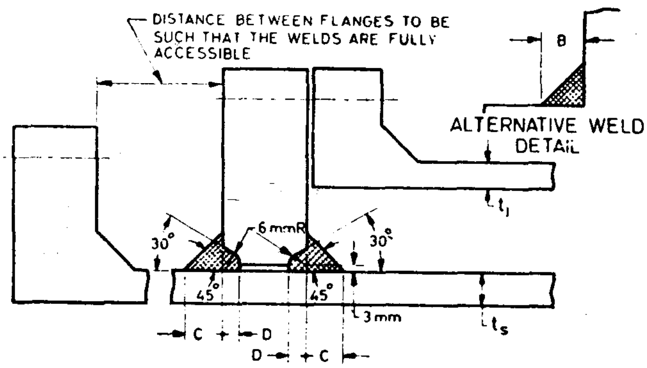
FIG. G.55 JACKETED CONNECTIONS



a) Attachment of jacket where a flanged connection is desirable.

b) *See* Fig. G.41 and G.43 for details of weld for attachment of the flanges.

FIG. G.56 JACKETED CONNECTIONS



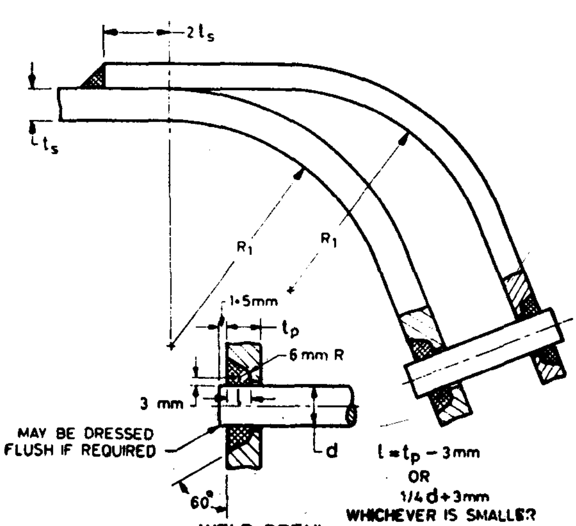
Fillet only	t_s	5	6	8	10	11	13	14	16	18	19	22	25	29	32	35	38
	B	8	10	12	14	15	18	20	21	23	27	—	—	—	—	—	—
Fillet and above	C	—	—	—	—	—	—	15	15	20	20	21	25	25	25	25	25
	D	—	—	—	—	—	—	6	8	8	10	11	12	17	21	27	31

a) Attachment of jacket where a flanged connection is desirable and where the vessel wall thickness does not exceed 38 mm.

b) Weld dimensions are minimum.

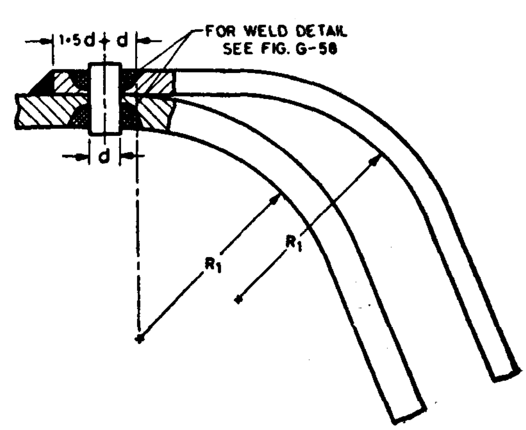
All dimensions in millimetres.

FIG. G.57 JACKETED CONNECTIONS



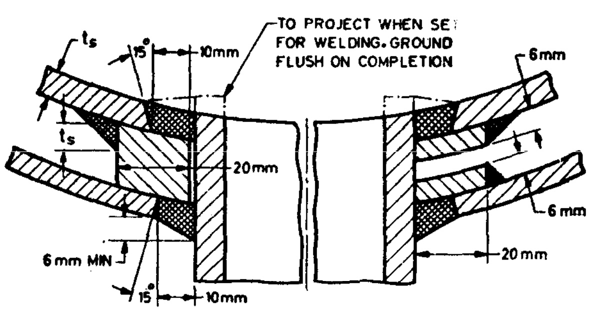
(For class 3 vessels only)

FIG. G.58 JACKETED CONNECTIONS



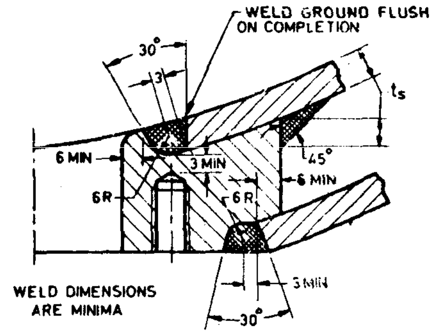
(For class 3 vessels only)

FIG. G.59 JACKETED CONNECTIONS



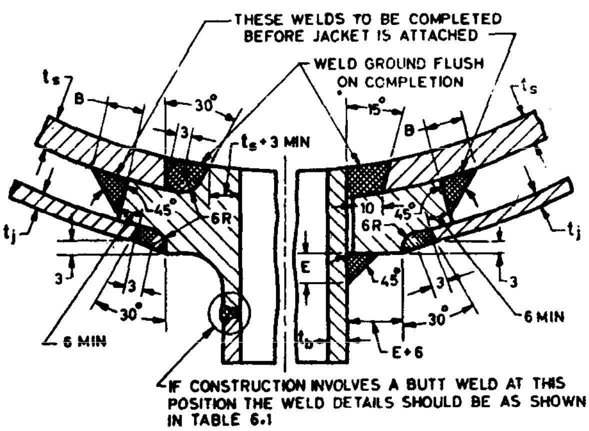
a) Flush type branch attachment using a block (left-hand side) or backing rings (right-hand side)
b) Weld dimensions are minimum.

FIG. G.60 PERMISSIBLE THROUGH CONNECTION FOR JACKETED VESSELS



All dimensions in millimetres.

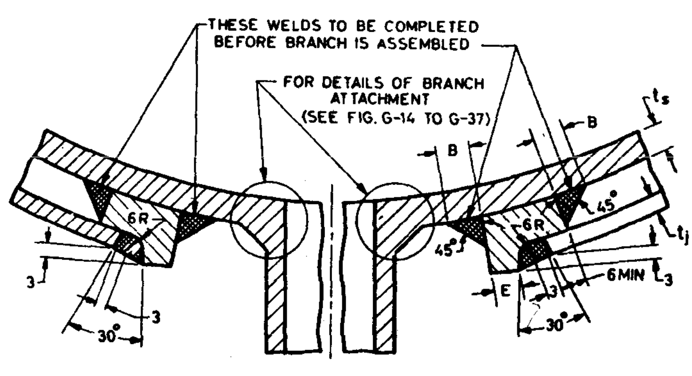
FIG. G.61 PERMISSIBLE THROUGH CONNECTION FOR JACKETED VESSELS



t_b	5	6	8	10	11	13	14	15	18	20	t_s
E	8	10	12	14	15	17	20	21	23	27	B

All dimensions in millimetres.

FIG. G.62 PERMISSIBLE THROUGH CONNECTION FOR JACKETED VESSELS



$E = t_j + 3$ MIN

Weld dimensions are minimum.

t_s	3	5	6	8	10	11	13	14	16	18	22
B	6	8	10	12	14	15	17	20	23	24	27

All dimensions in millimetres.

FIG. G.63 PERMISSIBLE THROUGH CONNECTION FOR JACKETED VESSELS

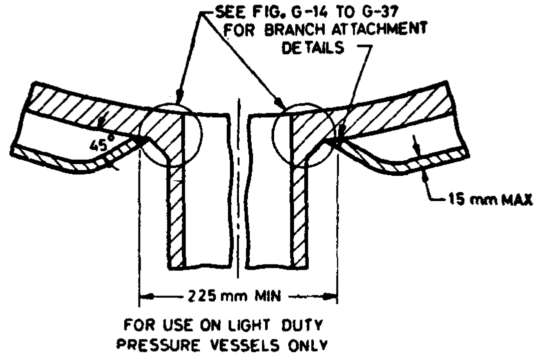
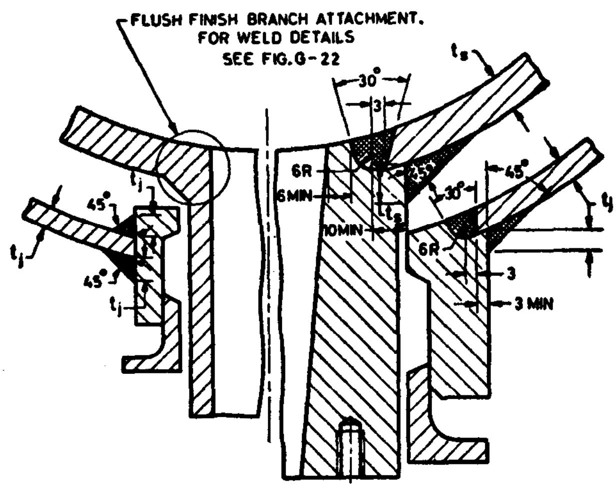
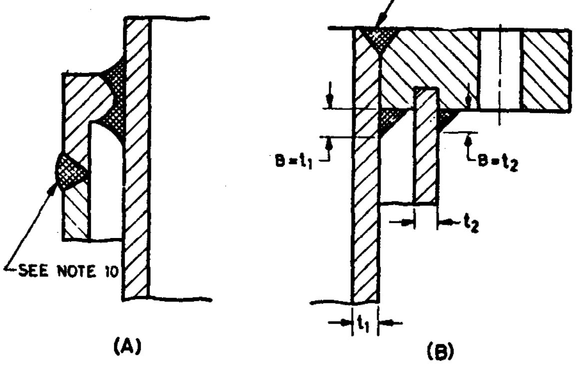


FIG. G.64 PERMISSIBLE THROUGH CONNECTION FOR JACKETED VESSELS



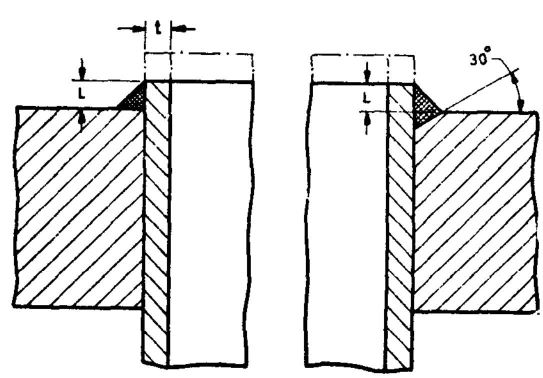
Weld dimensions are minimum.
All dimensions in millimetres.

FIG. G.65 PERMISSIBLE THROUGH CONNECTION FOR JACKETED VESSELS



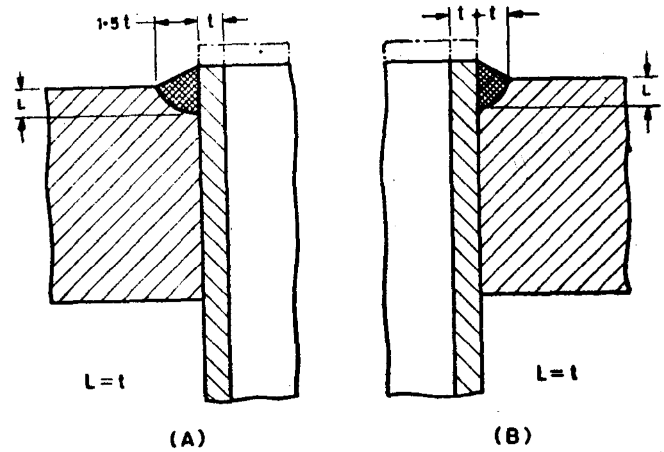
See Notes on page 223.

FIG. G.66 CONNECTION BETWEEN JACKET AND SHELL



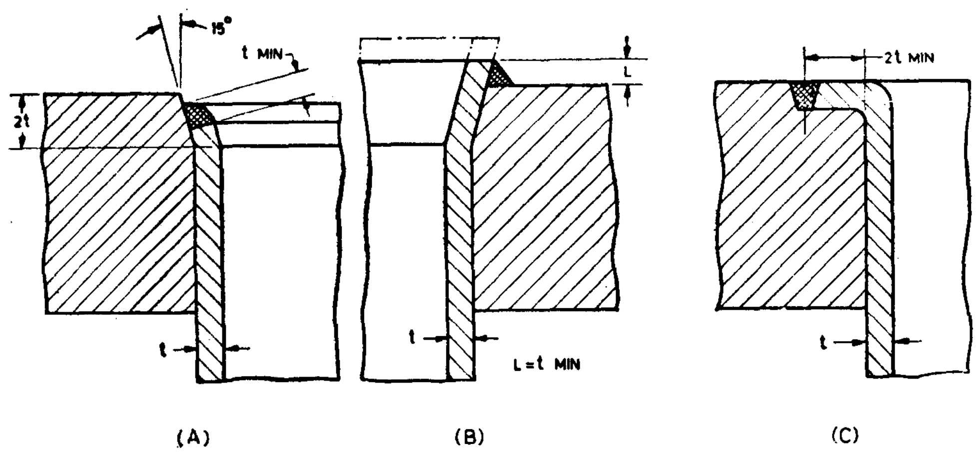
a) Tube wall thickness $t = 3$ mm *Min.* Weld size $L = t$ *Min.*
b) Minimum distance between tubes = 2·5 t or 7·5 mm whichever is greater.
c) The tube ends should be slightly expanded to not more than 90 percent of depth to fill the holes.
d) If the end of the tube projects beyond the weld, the projecting position should be removed after welding.
e) It may be necessary to deposit the weld in two runs to ensure a tight joint if the operating conditions are onerous.

FIG. G.67 TUBE-TO-TUBE PLATE CONNECTIONS



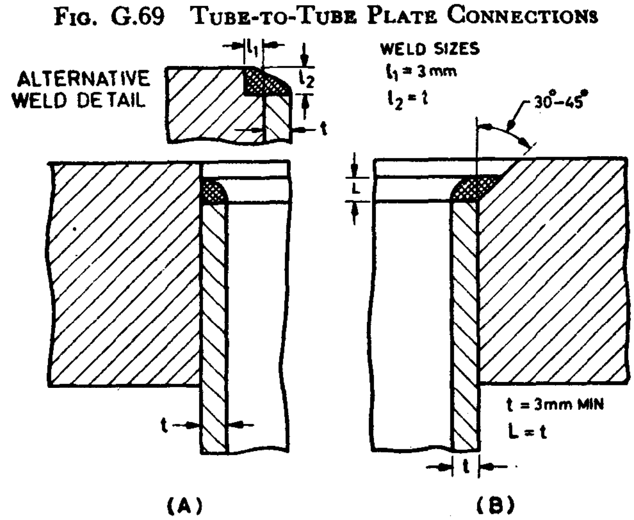
a) The tube ends should be slightly expanded to not more than 90 percent or depth to fill the holes.
b) If the end of the tube projects beyond the weld, the projecting portion should be removed after welding.
c) It may be necessary to deposit the weld in two runs to ensure a tight joint if the operating conditions are onerous.
d) The preparation shown in Fig. G.68A and G.68B should be preferred where there is danger of burning through the tube wall due to its thinness.

FIG. G.68 TUBE-TO-TUBE PLATE CONNECTIONS



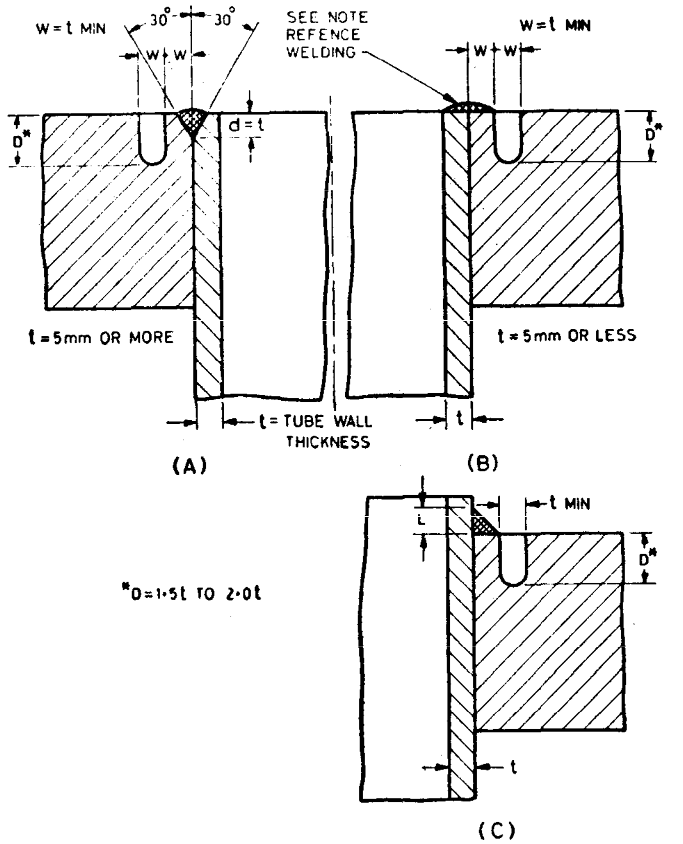
a) If the end of the tube projects beyond the weld, the projecting portion should be removed after welding.
b) This detail is based on the practice followed in certain cases.

FIG. G.69 TUBE-TO-TUBE PLATE CONNECTIONS



a) The tube ends should be slightly expanded to fill the hole.
b) These details are permissible for low operating pressures and small degrees of fluctuation in operating temperature.

FIG. G.70 TUBE-TO-TUBE PLATE CONNECTIONS



a) The tube ends should be slightly expanded to fill the hole not more than 90 percent of the depth.

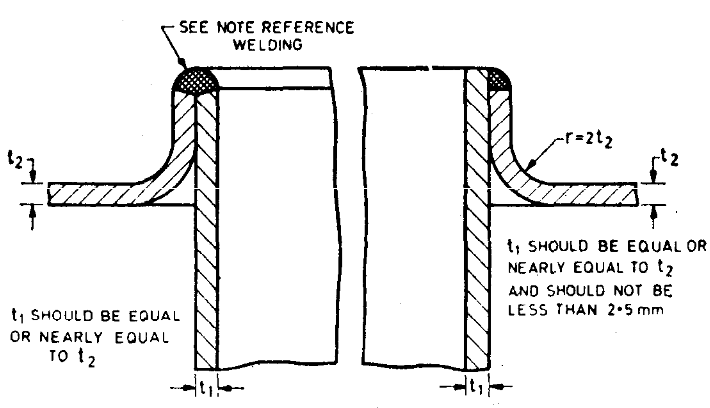
b) When using this detail special care should be taken to ensure that the tube plate is not laminated.

c) *Reference Welding*

The detail shown in Fig. G.71B is suitable for welding by processes other than the metal arc process. A filler rod should be used if the tube wall thickness exceeds 1·5 mm when oxy-acetylene gas welding is employed and 2·0 mm when other suitable arc welding processes are used, such as atomic hydrogen or inert gas are welding.

d) These details are recommended for use when it is required to minimize the deformation of the tube plate due to welding.

FIG. G.71 TUBE-TO-TUBE PLATE CONNECTIONS



a) It is uncommon for this detail to be used if t_1 or t_2 exceeds 4 mm.

b) *Reference Welding*

The detail shown in Fig. G.70 is suitable for welding by processes other than the metal arc process. A filler rod should be used if the tube wall thickness exceeds 1·5 mm when oxy-acetylene gas welding is employed and 2·0 mm when other suitable arc welding processes are used, such as atomic hydrogen or inert gas arc welding.

FIG. G.72 TUBE-TO-TUBE PLATE CONNECTIONS

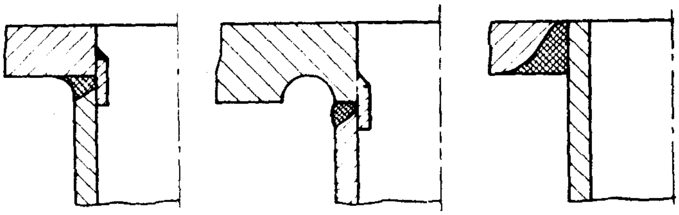
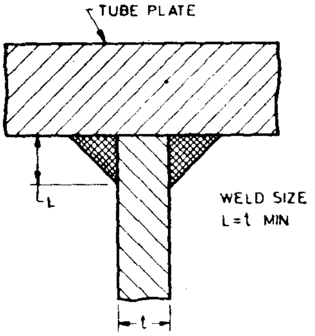


Fig. G.73 Tube-to-Tube Plate Connections



If L exceeds 15 mm, preference should be given to the detail shown in Fig. G.75.

Fig. G.74 Tube Plate to Shell Connections

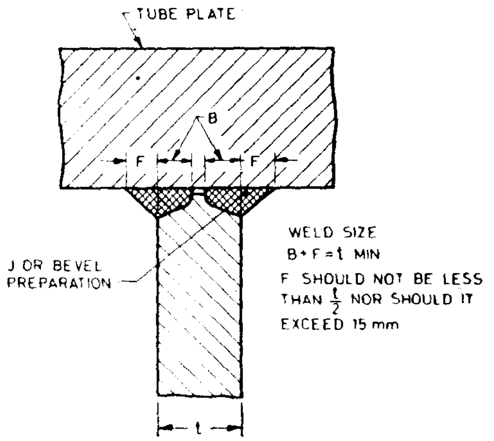
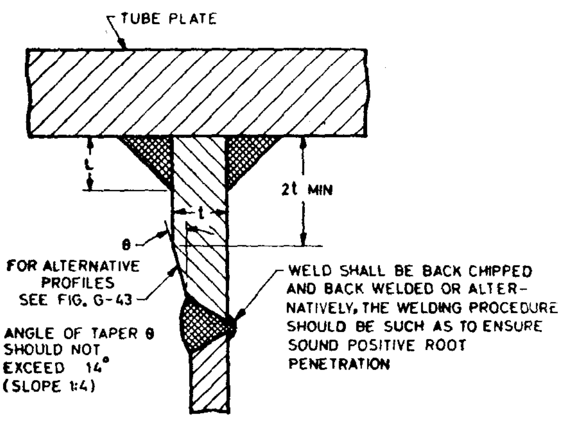


Fig. G.75 Tube Plate to Shell Connections



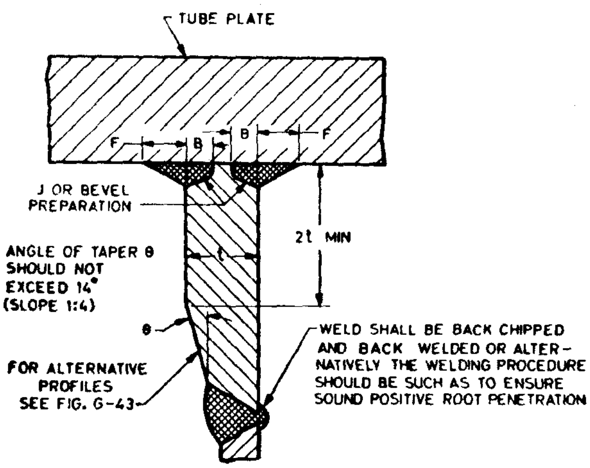
Weld size:

$L = t$ *Min*.

If L exceeds 15 mm, preference should be given to the detail shown in Fig. G.77.

Its use to be avoided when thermal gradient may cause overstress in welds.

Fig. G.76 Tube Plate to Shell Connections

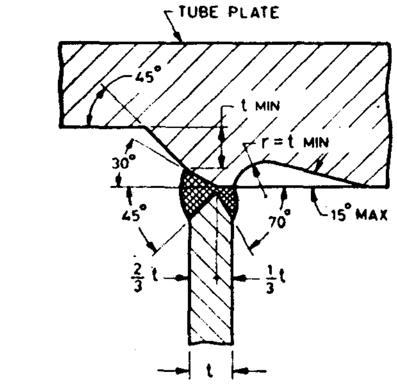


Weld size:

$B + F = t$ *Min*.

F should not be less than $t/2$ nor should it exceed 15 mm.

Fig. G.77 Tube Plate to Shell Connections

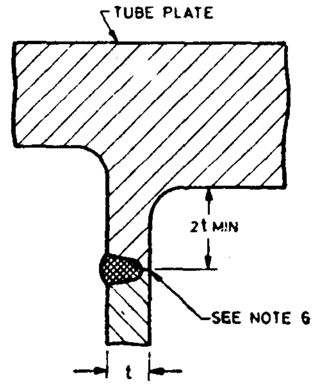


a) When using these details special care shall be taken to ensure that the tube plate is not laminated.

b) Accessible for welding on both sides of the shell.

(For forged shapes only)

FIG. G.78 TUBE PLATE TO SHELL CONNECTIONS

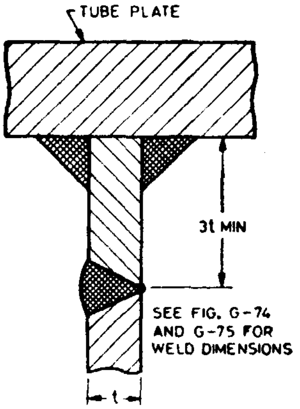


a) Alternative preparation may be used but the welding procedure should be such as to ensure sound positive root penetration in the butt joint if made from the outside only.

b) Accessible for welding on both sides of the shell.

(For forged shapes only)

FIG. G.79 TUBE PLATE TO SHELL CONNECTIONS

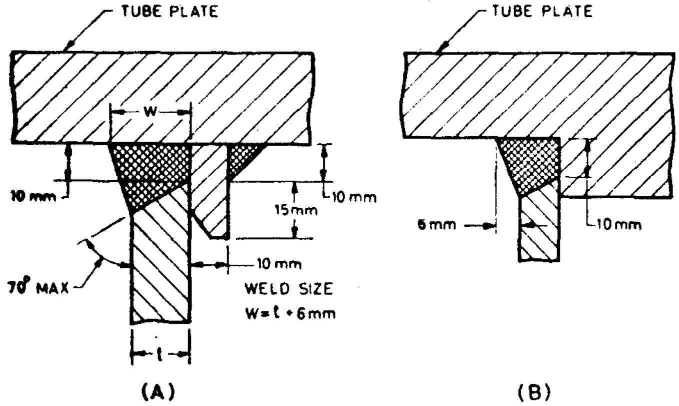


a) Alternative preparation may be used but the welding procedure should be such as to ensure sound positive root penetration in the butt joint.

b) Use when thermal gradient may cause overstress in welds.

c) Accessible for welding on one side of the shell only.

FIG. G.80 TUBE PLATE TO SHELL CONNECTIONS



This detail is recommended for non-corrosive operating conditions only.

FIG. G.81 TUBE PLATE TO SHELL CONNECTIONS

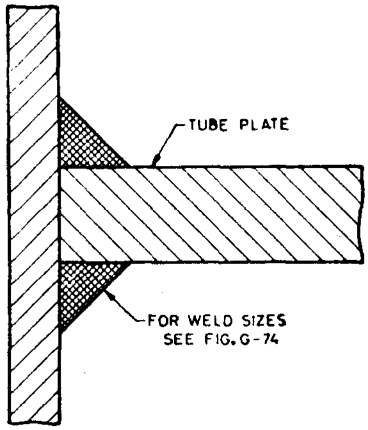
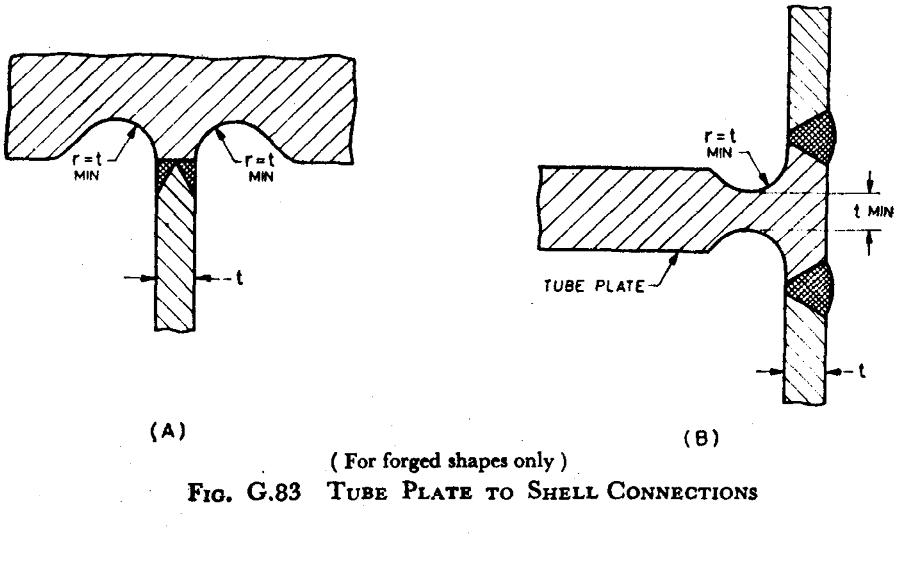
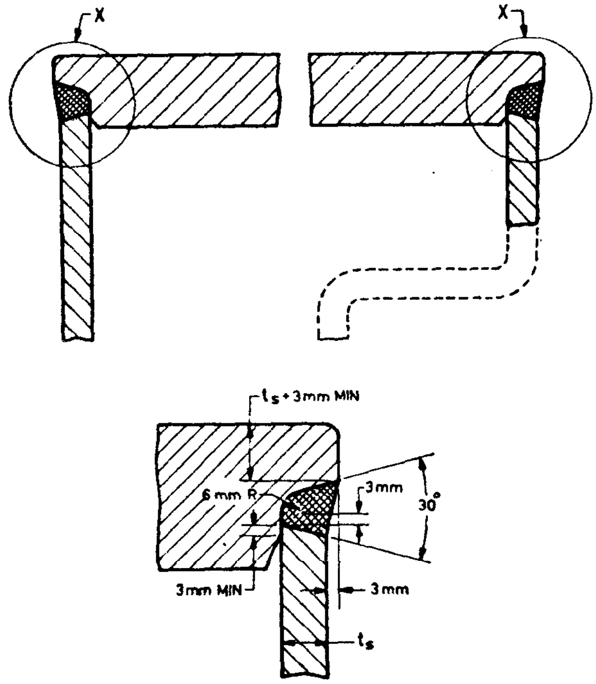


FIG. G.82 TUBE PLATE TO SHELL CONNECTIONS



(For forged shapes only)

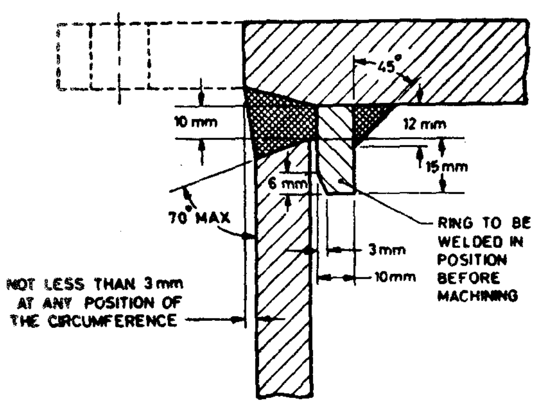
FIG. G.83 TUBE PLATE TO SHELL CONNECTIONS



DETAIL AT X

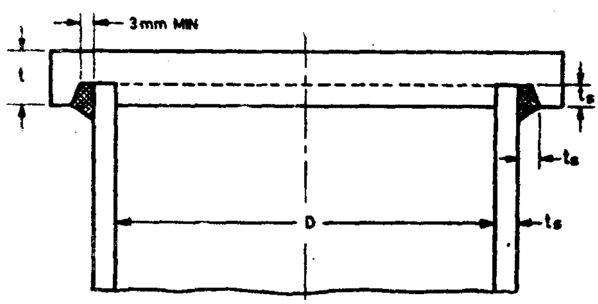
a) Weld profiles are diagrammatic only.
b) The hazard of weld cracking shall be taken into consideration.

Fig. G.84 Flat Ends and Covers



a) Weld profiles are diagrammatic only.
b) The hazard of weld crackings shall be taken into consideration.

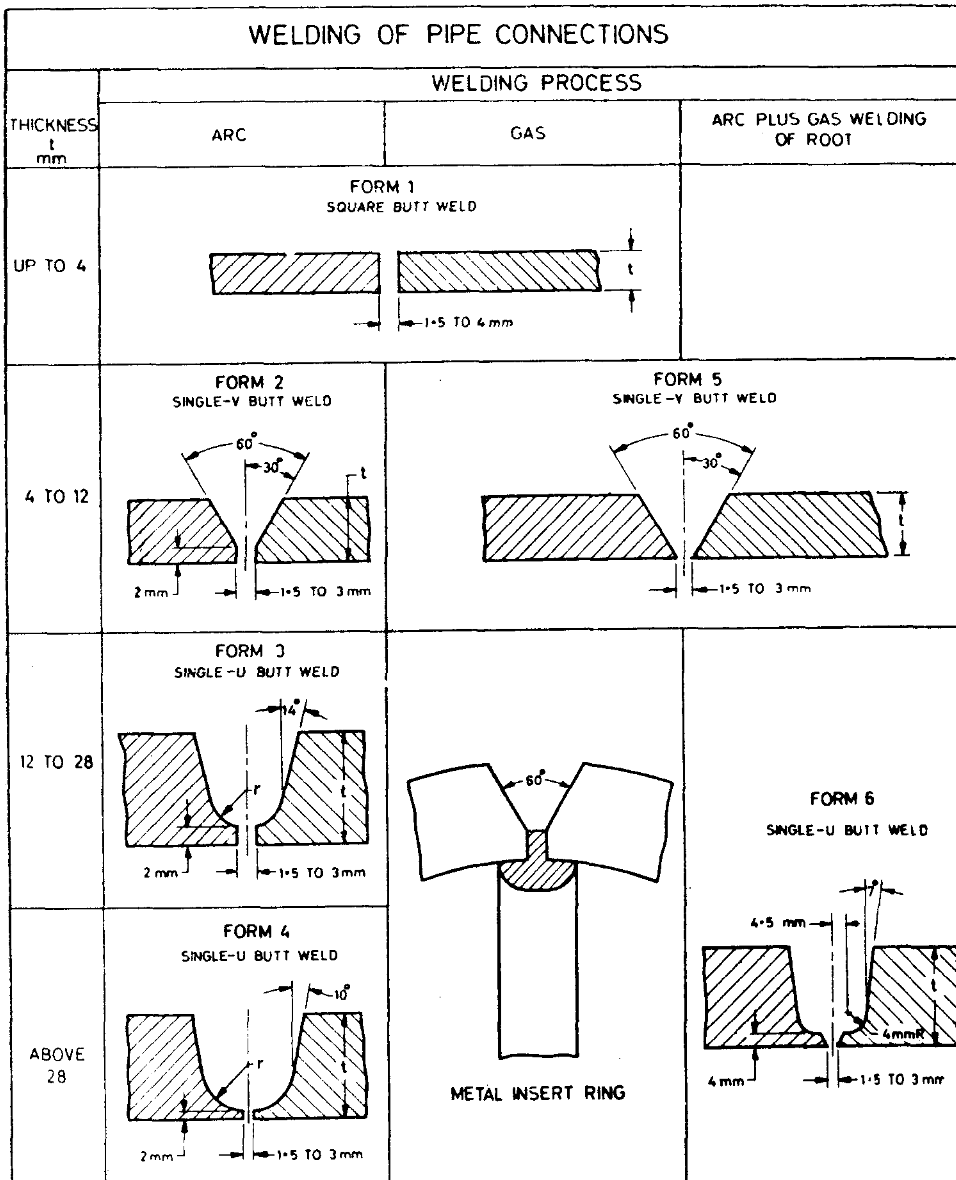
Fig. G.85 Flat Ends and Covers



t NOT LESS THAN $2t_s$

a) Weld profiles are diagrammatic only.
b) The hazard of weld cracking shall be taken into consideration.

Fig. G.86 Flat Ends and Covers

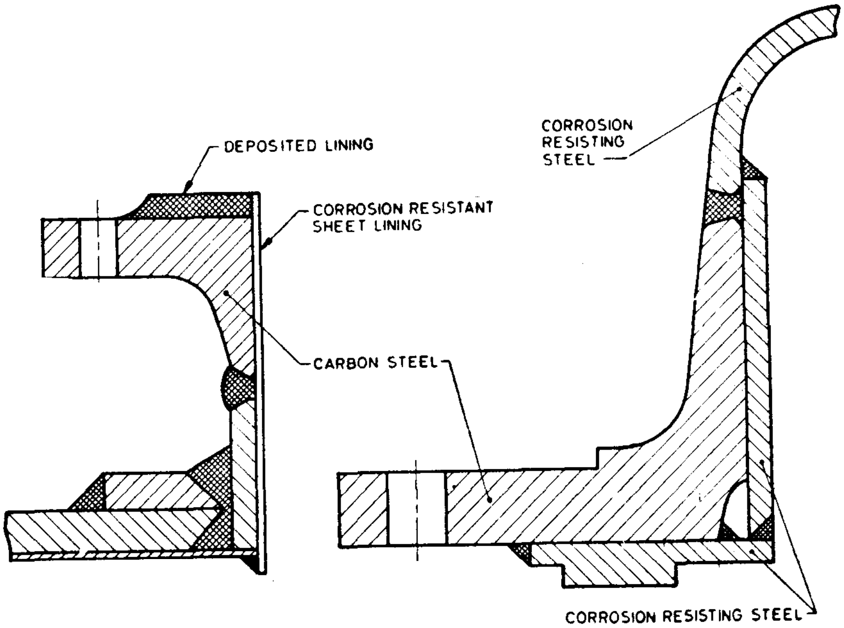


a) These forms of gap apply to both unalloyed and low-alloy steels.

b) The thickness limits indicated in the table for the various forms of gap and welding methods are for guidance only.

c) Gap widths depend both on the thickness and diameter of the pipe and on the type of filler wire used. The gap widths indicated in the table are for guidance only.

Fig. G.87 Welding of Pipe Connections



(A) (B)

FIG. G.88 EXAMPLE OF LINING OF VESSELS

GENERAL NOTES*

1. In general it is recommended that the ratio of the branch to shell thickness shall be limited as follows: t_b/t should not be less than 1/5.
2. In all these details this branch should be a loose fit in the hole but the gap at any point should not exceed 3 mm or $t_b/2$ whichever is the lesser.
3. Special precautions should be taken to minimize the stresses induced by welding particularly when the shell thickness exceeds about 20 mm.
4. When using this detail special care should be taken to ensure that the shell plate is not laminated.
5. These connections may also be used when there is accessibility for welding.
6. Weld shall be back chipped and back welded or alternatively the welding procedure should be such as to ensure sound positive root penetration.
7. The hole may be omitted to facilitate pressure testing.
8. A similar connection may be used with an internal reinforcing ring.
9. Alternative detail permissible provided the thickness or the branch of shell, whichever is the lesser, does not exceed 20 mm.
10. *J* or bevel preparation.
11. Weld size $B + F = 1{\cdot}5\ t_b$ *Min* or $1{\cdot}5\ t$ *Min* whichever is less; F should not exceed 16 mm nor be less than $t_b/2$.
12. Weld size $L = 1{\cdot}5\ t_b$ *Min* or $1{\cdot}5\ t$ *Min* whichever is the lesser. L should not be greater than 16 mm. When $1{\cdot}5\ t_b$ or $1{\cdot}5\ t$ whichever is less, exceeds 16 mm use details shown in Fig. G.23.
13. Weld sizes $B_1 + F_1 = 1{\cdot}5\ t_b$
    $F_2 = 1{\cdot}5\ t_b$
    $B_e = 1{\cdot}5\ t_b$
    F_1 and F_2 should not exceed 16 mm nor be less than $t_b/2$.

The intent of the limitation in the size of the fillet weld is to maintain the stress field induced by welding within reasonable limits

14. Weld sizes $B_1 + F_1 = 1{\cdot}5\ t_b$
    $B_2 = 1{\cdot}0\ t_b$
    $F_2 = 1{\cdot}5\ t_b$
    $F_3 = 1{\cdot}5\ t_b$
    $L = 1{\cdot}5\ t_r$
    F_1 and F_e should not exceed 16 mm nor be less than $t_b/2$.
15. A smaller limitation in weld size of $L = 1{\cdot}0\ t_b$ *Min* or $1{\cdot}0\ t$ *Min* whichever is less, may also be used.
16. A smaller limitation in weld size or $B + F = 1{\cdot}0\ t_b$ *Min or* $1{\cdot}0\ t$ *Min* whichever is less, may also be used.
17. A smaller limitation in weld size of $B + F$ and F_1 equal to $1{\cdot}0\ t$ *Min* may also be used.

*These notes refer to the notes mentioned in the figures given in this Appendix.

APPENDIX H

(*Clauses* 6.2.4, 6.2.5, 7.1.10 *and* 7.2.11)

PRO FORMA FOR THE RECORD OF WELDING PROCEDURE QUALIFICATION/ WELDER PERFORMANCE QUALIFICATION TEST

Record of .... Date .... No. ....

Contractor/Manufacturer .... Address ....

Welding Operator: Name .... Father's Name .... Date of Birth ....

Designation .... Identification Number/Symbol...

Material ....Specification ....Tensile Strength ....
(Plate or Pipe)

Electrode Type .... Specification .... Welding Process.............. Manual or Machine..............

Type of Flux .... Inert gas .... Type of backing used ....

Type of Joint.......................Single or Multiple pass.................Amperes..............Volts..............m per min........

Material Thickness ....mm. Welding Position ....
(If pipe, dia and wall thickness)

Preheat Temperature Range..Post Heat Treatment ....

Thickness range this test qualifies ....

Welding done in accordance with Manufacturer's/Client's Specification No. .... Date ....

1. REDUCED-SECTION TENSILE TEST

Specimen No.	Dimensions, mm: Width	Dimensions, mm: Thickness	Area mm^2	Gauge Length mm	Ultimate Load, kgf	Tensile Strength kgf/mm^2	Yield Point	Elongation percent	Character of Failure and Location	Remarks
...	...	...	...	...	...	...	...	...	...	...

2. ALL-WELD METAL TENSILE TEST

Specimen No.	Dimensions, mm Diameter	Area mm^2	Gauge Length mm	Ultimate Load, kgf	Tensile Strength kgf/mm^2	Yield Point	Elongation percent	Character of Failure and Location	Remarks
...	...	...	...	...	...	...	...	...	...

3. GUIDED FACE-BEND TEST (TRANSVERSE)

Specimen No.	Angle of Bend	Former Radius mm	Thickness of Specimen mm	Description, Location, Nature and Size of any Crack or Tearing of Specimen	Remarks
...	...	...	...	...	...

4. GUIDED ROOT-BEND TEST (TRANSVERSE)

Specimen No.	Angle of Bend	Former Radius mm	Thickness of Specimen mm	Description, Location, Nature and Size of any Crack or Tearing of Specimen	Remarks
...	...	...	...	...	...

5. GUIDED SIDE-BEND TEST (TRANSVERSE)

Specimen No.	Angle of Bend	Former Radius mm	Thickness of Specimen mm	Description, Location, Nature and Size of any Crack or Tearing of Specimen	Remarks
....	....	....	....	....	....

6. NICK-BREAK TEST

Specimen No.	Type/Depth Nick	Specimen Thickness mm	Description, Appearance of Fracture	Result
....	....	....	....	....

7. IMPACT OR NOTCHED BAR TEST

Specimen No.	Type/Depth of Notch	Specimen	Test Temperature °C	Impact Values kgf.m/cm²	Appearance of Fracture	Remarks
....	....	....	....	....	....	....

8. FILLET WELD-TEST

Specimen No.	Specimen, Size and Thickness mm	Fillet Size Leg Length mm	Welding Position	Test Results					Remarks
				Fracture test appearance	Length & percent of defects mm %	Micro test fusion	Fillet size mm	Convexity or concavity mm	
....	....	....	....	....	....	....	....	....	....

9. MACRO EXAMINATION & HARDNESS TEST

Specimen	Type of Etchant	Observation	Vickers Hardness			Remarks
			Parent metal	Weid metal	Heat affected zone	
....	....	....	....	....	....	....

The undersigned manufacturer/contractor certifies that the statements made in this report are correct and that the test welds were prepared, welded and tested in accordance with the requirements of IS : 2825 - 1969.

Test Witnessed by .... Signature ....

Inspecting Authority

Office Seal

For and on behalf of...........
(Contractor/Manufacturer)

Date ....

Date ....

APPENDIX J

(*Clause* 6.7.28)

WELDING OF CLAD STEEL AND APPLICATION OF CORROSION-RESISTANT LININGS

J-1. GENERAL

J-1.1 Clad steel is generally used where unalloyed steel alone does not withstand the corrosive attack, nor the required thickness of corrosion-resistant alloys could be provided for economical reasons. The provisions of this appendix are applicable to welding of steels clad with chrome and chorme-nickel steels, nickel, copper-nickel and nickel alloys or copper alloys, by open arc fusion, inert gas metal arc or submerged arc welding processes. The rules of this appendix are applicable to pressure vessels or vessel parts that are constructed of integrally clad plate, and to vessels and vessel parts that are fully or partially lined inside or outside with corrosion-resistant plate, sheet or strip attached by welding to the base plates before or after forming, or to the shell, heads and other parts during or after assembly into the completed vessel.

J-1.1.1 The provisions of this appendix do not apply when cladding or lining is deposited by fusion welding processes with stick or strip electrodes and for fitting of renewable wear plates to arrest local erosion or abrasion.

J-1.2 If the corrosion resistance of the clad side is to be maintained when the workpiece is completed, it is essential that the deposited metal on the clad side should be not less corrosion resistant than the cladding itself. The weld shall be at least as thick as the cladding and in regard to corrosion resistance its composition shall match that of the cladding. To achieve this, at least two runs shall be put in. As a general rule the backing metal should be welded first and with a filler of like kind. While this is being done, care shall be taken to avoid melting the cladding with the filler used in welding the backing metal. The danger of dilution of the alloy contents of clad material or lining by welding from the clad or lined side increases with decreasing thickness of clad material or lining. The plate edges shall be prepared accordingly. In the case of thin plate clad with austenitic steel, the entire cross section may be welded with austenitic fillers, provided that no corrosion cracks occur in the weld junction on the backing side under the specified conditions of attack (for example, by aggressive media combined with the action of steam). It shall be ensured without fail that unalloyed or low alloy fillers are not used for welding on high alloy cladding metal or high alloy weld metal. The welding conditions adopted (including, for example, the welding process, the weld form and the welding sequence) shall be chosen so as not to reduce the strength of the welded joint unduly. If heat treatment is necessary the properties of the backing metal and o. the cladding metal shall be taken into account.

J-1.3 Plates under 10 mm thick in the backing metal may also have the entire weld cross section welded with austenitic filler metal provided that the temperature experienced in service does not exceed 200°C. In situations where welding from the clad side is not practicable (for example, in pipes), the weld preparation should be carried out in the manner given in Fig. J.1. The cladding metal is welded with chrome steel or chrome-nickel steel filler metal of like kind. The subsequent runs may be welded with austenitic filler metal if the backing metal is to be welded with filler metal of like kind, however, then the intermediate runs shall be welded with a filler which will guarantee that the weld metal is free of cracks and possesses the same strength and ductility.

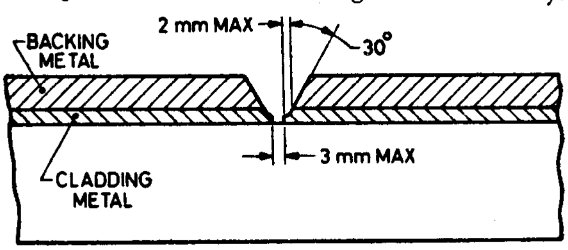


Fig. J.1 Method of Edge Preparation for Welding Clad Steel

J-2. FABRICATION

J-2.1 Preparation — The clad material should be protected against mechanical damages and from the inclusion of foreign material. While shearing clad plates the clad side should be upwards, so that the burrs or ridges are built on the base metal side. The cut edges shall be ground smooth.

Clad steels may be flame-cut from the base metal side, provided proper care has been taken in the selection of cutting speed, gas pressure and nozzle size. Preheating prior to the start of flame-cutting is advisable in certain cases. Flame-cutting with iron powder may be of considerable advantage, if cutting from clad material side is necessary. While flame-cutting, considerations should be given to the effects of flame-cutting on clad material particularly in the neighbourhood of kerf. Cleaning of chromium-nickel or stainless steel clad material or linings before successive runs should be done with stainless steel brushes to avoid inclusion.

J-2.2 Joints in Cladding Applied Linings — The types of joints and welding procedure used shall be such as to minimize the formation of

brittle weld composition by the mixture of metals of corrosion-resistant alloy and the base material.

NOTE — Because of different thermal coefficients of expansion of dissimilar metals, caution should be exercised in design and construction under the provisions of this appendix in order to avoid difficulties in service under extreme temperature conditions, or with unusual restraint of parts, such as may occur at points of stress concentration.

J-2.3 Inserted Strips in Clad Material — The thickness of inserted strips used to restore cladding at joints shall be equal to that of the nominal minimum thickness of cladding specified for the plates backed, if necessary, with corrosion-resistant weld metal deposited in the groove to bring the insert flush with the surface of the adjacent cladding.

J-2.4 Butt Welds in Clad Plates — For steel clad with resistant chrome steel and austenitic chrome-nickel steel, the requirements shall apply separately to the base plate and to the cladding. The thickness specified in Table 7.2 shall apply to the total thickness of the clad plates (*see also* Tables J.1 and J.2).

J-2.4.1 The welding procedure for butt welds in integrally clad plate shall be qualified as provided in **J-2.3** when any part of the cladding thickness of clad plate is included in the design calculations in **3**. When the cladding thickness is not included in the design calculation, the procedure for butt welds may be qualified as in **J-2.4** or the weld in the base plate joint may be qualified by itself in accordance with **7.1** and the weld in the cladding joint by itself in accordance with **J-2.7**.

J-2.5 Fillet and Composite Welds — Fillet welds of corrosion-resistant metal deposited in contact with two materials of dissimilar composition may be used for shell joints and attachments of various connections as permitted under the respective provisions of this code. In all types of joints and their forms, it should be ensured that there is a continuity of the clad material and the heat-affected zones are sound. The qualification of welding procedures and welders to be used on fillet and composite welds for a given combination of materials and alloy weld metal shall be in accordance with **7.1** and **7.2**.

J-2.6 Alloy Welds in Base Metals — Butt joints in base metal plates and parts may be made between corrosion-resistant alloy steel filler metal, or the joints may be made between corrosion-resistant alloy steel and low carbon or low alloy steel provided the welding procedure and the welders have been qualified in accordance with **7.1** and **7.2** for the combination of materials used. Some applications of this rule are base metal welded with alloy steel electrodes, and alloy nozzles welded to steel shelves.

J-2.7 Corrosion-Resistant Weld Deposits — Construction in which deposits of corrosion-resistant alloy weld metal are applied as a protective covering on the surface of base metal plates and parts and overwelded base metal joints, whether adjacent or not to the edges of lining sheets or cladding material, shall be qualified in accordance with **J-2.7.1** to **J-2.7.5**.

J-2.7.1 The qualification test plate shall consist of a base plate not less than 300 mm long, 150 mm wide, and 6 mm thick, to which are clamped or bonded two strips of lining or cladding material separated by a gap left in the lining or a groove cut in the cladding. The gap or groove shall run lengthwise of the test plate, approximately midway of the plate width. The nominal thickness of the lining or cladding shall be within 20 percent plus or minus of the thickness to be used in construction.

J-2.7.2 The width of gap shall be not less than twice the nominal thickness of the lining or cladding and not less than the maximum gap to be used in construction, but need not be greater than 20 mm in order to qualify welding procedures in which the corrosion-resistant weld metal is deposited in contact with base metal and adjacent lining or cladding material on two sides of a gap, as in welding the joints in liner sheets or clad plates.

J-2.7.3 The width of gap shall be not less than 20 mm in order to qualify welding procedures in which corrosion-resistant weld metal is deposited in contact with base metal with lining or cladding material on one side only as in layering corrosion-resistant weld metal on flange facings, or in making fillet welds.

J-2.7.4 The weld joint shall be made between the edges of the lining or cladding material by the procedure to be used in construction. The cooling of the test plate and any subsequent heat treatment shall follow the procedure to be used in construction.

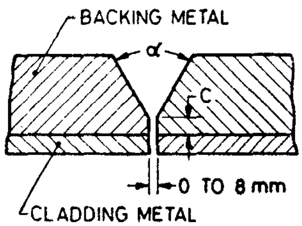
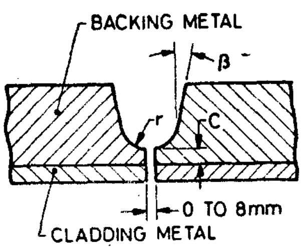
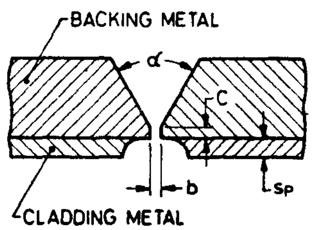
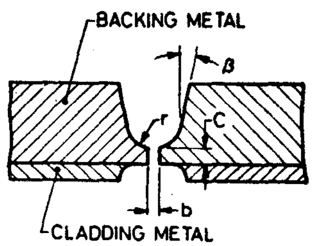
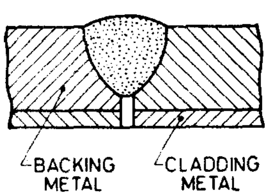
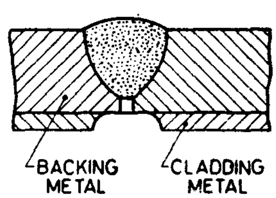
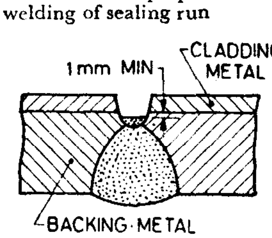
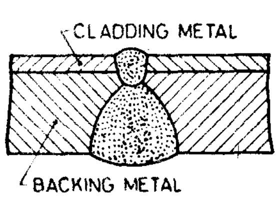
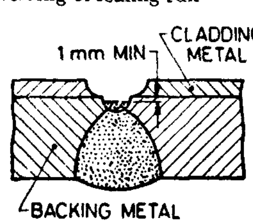
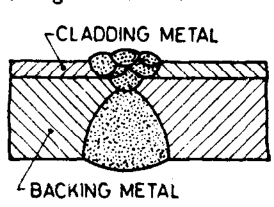
J-2.7.5 The tests to qualify the welding procedure shall be performed on two longitudinal bend test specimens that conform to the dimensions and other requirements specified under **7.1.5**. The specimens shall be tested in accordance with, and meet the requirements of **8.6**.

J-2.8 Attachment of Applied Linings — Applied linings may be attached to the base plate and other parts by any methods and processes of welding that are not excluded by this code. The welding procedure to be used in attaching applied linings to base plates and the method of determining the security of the attachment shall be a matter for agreement between the user and the manufacturer.

J-2.8.1 Each welding procedure to be used for attaching lining material to the base plate shall be qualified on lining-attachment welds made in the form and arrangement to be used in construction and with materials that are within the range of chemical composition of the material to be used for the base plate, the lining and the weld metal. Welds shall be made in each of the position that

TABLE J.1 WELDING OF STEEL CLAD WITH RUST-RESISTANT CHROME STEEL AND AUSTENITIC CHROE-NICKEL STEEL

(*Clause* J-2.4)

Opera-tion No.	A For all Thicknesses of Cladding Metal	B For Thicknesses of Cladding Metal $>$ 2·5 mm	Remarks
1.	Backing side weld preparation: Single-V butt weld  Single-U butt weld  	Backing side weld preparation: Single-V butt weld  Single-U butt weld  	Single-V or single-U butt weld at option: Single-V butt weld $\alpha = 60°$ $b = 2$ mm *Max* Single-U butt weld $b = 2$ mm *Max* $r = 4$ mm When open arc welding by hand is used, c is made half the thickness of the metal which must be deposited to put in the first run. For semi-mechanical and fully mechanized inert-gas, submerged-arc and other welding processes, it may be necessary to provide a larger gap between the root faces. For method B, the sides adjoining the root face must be clear of cladding metal for a distance $\geqslant$ 2 mm.
2.	Welding the backing side  	Welding the backing side  	Welding with filler metal of like kind. When welding the root, the cladding metal should not be penetrated.
3.	Clad side weld preparation and welding of sealing run  Welding the clad side  	Clad side weld preparation and welding of sealing run  Welding the clad side  	Cut out the root deep enough to ensure that: a) the weld metal on the backing side is reached, and b) slag inclusions and cracks in the root are eliminated. Weld the sealing run with a filler metal suited to the backing metal (*see* diagram) or, if necessary, with a filler metal giving a tough intermediate layer. The sealing run should be kept at least 1 mm below the cladding metal. After the backing metal should be ground smooth (where necessary) before the cladding metal is welded. The first run of metal deposited on the clad side should be put in with a filler of like kind. a) Thin electrodes are needed for open arc welding, whilst thin filler rods and not too high a current are needed for the other welding processes. The diameter of the filler used for welding the austenitic root run should not exceed 3·15 mm for the downhand (*F*) and vertical (*V*) positions, or 4 mm for the horizontal-vertical (*H*) position. b) The welding current should be kept as low as possible. The bottommost root fun on the clad side may, if necessary, be welded with an austenitic filler having an analysis differing from that of the cladding material. The subsequent runs, however, should be welded with fillers of a kind matching the cladding as closely as possible, or at least having the same corrosion resistance.

are to be used in construction. One specimen from each position to be qualified shall be sectioned. polished and etched to show clearly the demarcation between the fusion zone and the base metal. For the procedure to qualify, the specimen shall show, under visual examination without magnification, complete fusion in the fusion zone and complete freedom from cracks in the fusion zone and in the heat-affected metal.

J-2.9 Thermal Stress Relief*

J-2.9.1 Vessels or parts of vessels constructed of integrally clad or applied corrosion-resistant lining material shall be stress-relieved when the base plate is required to be stress-relieved. In applying these rules the determining thickness shall be the total thickness of integrally clad plate and the base plate thickness having applied corrosion-resistant lining.

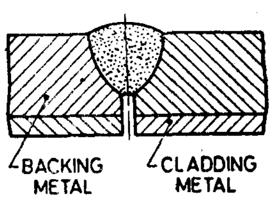
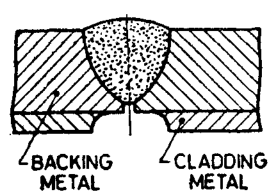
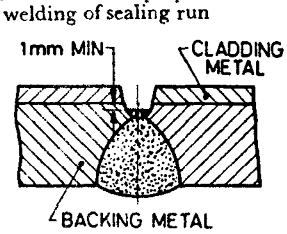
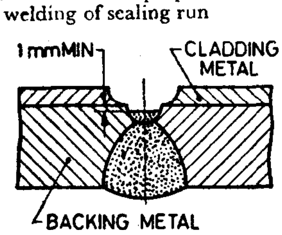
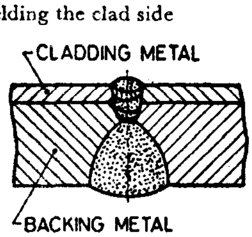
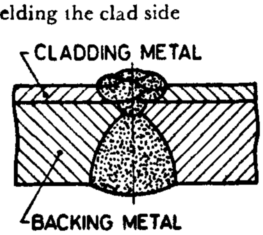
J-2.9.2 Vessels or parts of vessels constructed of chromium alloy stainless steel clad plate and those lined with chromium alloy stainless steel applied linings shall be stress-relieved in all thicknesses, except that such vessels need be stress-relieved only when required under **J-2.9.1** provided the cladding or lining joints are welded with austenitic stainless steel electrodes or a non-hardening nickel-chromium iron electrode and the composition of the cladding or lining material is within the specified limits with carbon content not exceeding 0·08 percent.

**Caution* : A 700°C stress-relieving treatment is within the sensitized carbide-precipitation range for unstabilized austenitic chromium-nickel steels, as well as within the range where sigma phase may form, and if used indiscriminately could result in material of inferior physical properties and inferior corrosion resistance which ultimately could result in failure of the vessel.

TABLE J.2 WELDING OF STEEL CLAD WITH NICKEL AND NICKEL ALLOYS AND WITH COPPER AND COPPER ALLOYS

(*Clause* J-2.4)

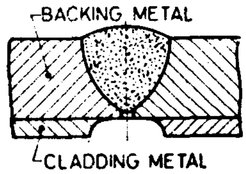
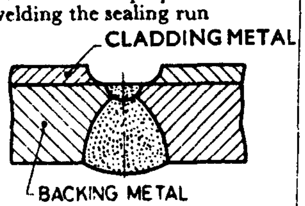
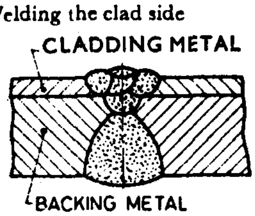
Nickel and Nickel Alloys

Operation No.	A For all Thicknesses of Cladding Metal	B For Thicknesses of Cladding Metal > 2·5 mm	Remarks
1.	*see* Table J.1		
2.	Welding the backing side 	Welding the backing side 	Welded with filler metal of like kind. If the cladding metal is not cut away, care shall be taken not to fuse it when welding the root run.
3.	Clad side weld preparation and welding of sealing run 	Clad side weld preparation and welding of sealing run 	Cut out the root deep enough to ensure that: a) the weld metal on the backing side is reached, and b) slag inclusions and cracks in the root are eliminated. Weld the sealing run with a filler metal identical in kind with the cladding or put in a sealing run (*see* diagram) with a high-nickel filler. The sealing run should be kept at least 1 mm below the cladding metal.
4.	Welding the clad side 	Welding the clad side 	The clad side should be welded with a filler corresponding to the cladding metal. To avoid undesirable mixing of the cladding weld metal with F_e, as many runs as possible should be put in, using thin filler rods with the current kept down to the lower limiting value. The filler metals used should give not more than 0·1 percent by weight of carbon in the weld metal. In the case of Monel fillers, up to 0·15 percent by weight can be tolerated.

(*Continued*)

TABLE J.2 WELDING OF STEEL CLAD WITH NICKEL AND NICKEL ALLOYS AND WITH COPPER AND COPPER ALLOYS — *Contd*

Copper and Copper Alloys

Opera-tion No.	B For all Thicknesses of Cladding Metal	Remarks
1.	*see* Table J.1	
2.	Welding the backing side 	Welded with filler metal of like kind.
3.	Clad side weld preparation and welding the sealing run 	Cut out root deep enough to ensure that: a) the weld metal on the backing side is reached, and b) slag inclusions and cracks in the root are eliminated. Weld the sealing run up to the level of the underside of cladding with a filler metal identical in kind with the backing metal.
4.	Welding the clad side 	The clad side should be welded with a filler corresponding to the cladding metal. The first layer should be put in with straight runs starting adjacent to one side of the cladding. Processes: manual arc welding and inert-gas arc welding. When inert-gas arc welding is used, the current must be kept as low as possible in order to minimize fusion of the backing metal. Light hammering of the weld while still red hot prevents the formation of contraction cracks.

J-2.10 Radiographic Examination

J-2.10.1 Pressure vessels or parts of vessels constructed of clad plate and those having applied corrosion-resistant linings shall be radiographed when required (*see* **8.7.1**). The plate thickness specified under this clause shall be the total plate thickness for clad construction and the base plate thickness for applied-lining construction.

J-2.10.2 *Base Plate Weld with Strip Covering* — When the base plate weld in clad or lined construction is protected by a covering strip or sheet of corrosion-resistant material applied over the weld in the base plate to complete the cladding or lining, any radiographic examination required under **8.7.1** may be made on the completed weld in the base plate before the covering is attached.

J-2.10.3 *Base Plate Weld Protected by Alloy Weld*— When a layer of corrosion-resistant weld metal is used to protect the weld in the base plate from corrosion, radiographic examinations required under **8.7.1** shall be made as follows after the joint, including the corrosion-resistant layer, is completed:

a) On any clad construction in which the total thickness of clad plate is used in the design calculations; and

b) On lined construction, and on clad construction in which the base plate thickness only is used in the design calculations, except as otherwise permitted under **J-2.10.4**.

J-2.10.4 The required radiographic examination may be made on the completed weld in the base plate before the corrosion-resistant alloy cover weld is deposited provided all of the following requirements are met:

a) The thickness of the base plate at the welded joint is not less than that required by the design calculations;

b) The weld reinforcement is removed down to the surface which is to be covered, leaving it flush with the adjacent base plate, reasonably smooth, and free from undercutting;

c) The corrosion-resistant alloy weld deposit is not air-hardening; and

d) The completed corrosion-resistant weld deposit is examined by spot-radiography as provided in **8.7.2**. Such spot-radiographic examination is to be made only for the detection of possible cracks.

J-2.11 Tightness of Applied Lining

J-2.11.1 A test for tightness of the applied lining that will be appropriate for the intended service is recommended, but the details of the test shall be a matter for agreement between the user and the manufacturer. The test should be such as to assure freedom from damage to the load-carrying base plate. When rapid corrosion of the base plate is to be expected from contact with the contents of the vessels, particular care should be taken in devising and executing the tightness test.

J-2.11.2 Following the hydrostatic pressure test, the interior of the vessel shall be inspected to determine if there is any seepage of the test fluid through the lining. Seepage of the test fluid behind the applied lining may cause serious damage to the liner when the vessel is put in service. When seepage occurs precautions as laid down in **J-2.11.3** shall be followed and the lining shall be repaired by welding. Repetition of the radiography, the heat treatment, or the hydrostatic test of the vessel after lining repairs is not required except when there is reason to suspect that the repair welds may have defects that penetrate into the base plate, in which case the inspector shall decide which one or more shall be repeated.

J-2.11.3 When the test fluid seeps behind the applied liner, there is danger that the fluid will remain in place until the vessel is put in service. In cases where the operating temperature of the vessel is above the boiling point of the test fluid, the vessel should be heated slowly for a sufficient time to drive out all test fluid from behind the applied liner without damage to the liner. This heating operation may be performed at the vessel manufacturing plant or at the plant where the vessel is being installed. After the test fluid is driven out, the lining should be repaired by welding.

APPENDIX K

[*Clauses* 7.2.4.1(B)(b)(2), 7.2.6.3(b) *and* 8.5.11]

METHOD OF PREPARING ETCHED SPECIMEN

K-1. GENERAL

K-1.1 The surfaces to be etched should be smoothed by filing or machining or by grinding on metallographic papers. With different alloys and tempers, the etching period will vary from a few seconds to several minutes and should be continued until the desired contrast is obtained. As a protection from the fumes, liberated during the etching process, this work should be done under a hood. After etching, the specimens should be thoroughly rinsed and then dried with a blast of warm air. Coating the surface with a thin clear lacquer will preserve the appearance.

K-2. ETCHANTS FOR FERROUS MATERIALS

K-2.1 Etching solutions suitable for carbon and low-alloy steels, together with directions for their use, are suggested as follows:

a) *Hydrochloric Acid* — Hydrochloric acid and water equal parts by volume. The solution should be kept at or near the boiling temperature during the etching process. The specimens are to be immersed in the solution for a sufficient period of time to reveal all lack of soundness that might exist at their cross-sectional surfaces.

b) *Ammonium Persulphate* — One part of ammonium persulphate to nine parts of water by weight. The solution should be used at room temperature and should be applied by vigorously rubbing the surface to be etched with a piece of cotton saturated with the solution. The etching process should be continued until there is a clear definition of the structure in the weld.

c) *Iodine and Potassium Iodide* — One part of powdered iodine, two parts of powdered potassium iodide, and ten parts of water, all by weight. The solution should be used at room temperature and brushed on the surface to be etched until there is a clear definition or outline of the weld.

d) *Nitric Acid* — One part of nitric acid and three parts of water by volume. (*Caution*: Always pour the acid into the water. Nitric acid causes bad stains and severe burns.) The solution may be used at room temperature and applied to the surface to be etched with a glass stirring rod. The specimens may also be placed in a boiling solution of the acid but the work should be done in a well-ventilated room. The etching process should be continued for a sufficient period of time to reveal all lack of soundness that might exist at the cross-sectional surfaces of the weld.

APPENDIX L

[*Clause* 8.7.10.1(e)]

PRO FORMA FOR REPORT OF RADIOGRAPHIC EXAMINATION

1. Name of manufacturer ....
2. Name of customer ....
3. Vessel No. .... Material .... Electrode ....

Certified that the radiographs of the welded joints in the above pressure vessel have been taken in the position shown as per specification/code ....

Office Seal

Signature of Manufacturer's Inspecting Authority

Serial No.	Radiograph No.*	Material thickness	Interpretation and Remarks

*For suggested method of numbering radiographs, *see* Note.

NOTE — *Numbering of Radiographs* (For use in 'Radiograph No.' column of the Report Sheets only).

In making the radiograph, lead characters should be used so that the resulting image shows the Vessel Number or other identifying number shown on the report and sufficient information to enable the radiograph number used in the report to be readily derived by inspection in accordance with the following:

a) The radiograph number used in the Report Sheet should commence with a numeral and letter indicating the number and type of seam radiographed, using the letters *L* and *C* to denote longitudinal and circumferential seams respectively.

Example:

1*C* would refer to circumferential seam, number 1.

2*L* would refer to longitudinal seam, number 2.

b) Following the above, and after a hyphen, numerals should be given to indicate the position of the radiograph along the seam. Where, for example, a radiograph shows the seams for the unit of length between positions 24 and 25, these reference numbers would be 24/25.

c) Following the above, where appropriate: The letters (*R*1), (*R*2), etc, in brackets, should be given to indicate where the radiograph is a retake which has been made following repairs made after consideration of the original radiograph: the film taken following each repair should be indicated by the numbers 1, 2, 3, etc.

The letter (*T. S.*), in brackets, should be given to indicate where a tube shift technique has been used, with two exposures on one film.

The letter (*S*), in brackets, should be given to indicate a second exposure taken at an angle.

The letter (*X*), in brackets, should be given to indicate a film which shows the radiograph of two intersecting welds: this letter need not appear on the film.

d) Examples of radiograph numbers based on the foregoing procedure would be:

2*C*-15/16 — indicating the radiograph covering the unit length between positions 15 and 16 on the second circumferential seam.

1*L*-31/32(*R*2) — indicating the radiographs covering the unit length between positions 31 and 32 on the first longitudinal seam following second repair.

APPENDIX M

(*Clause* 8.3.1.1)

PRO FORMA FOR MAKER'S CERTIFICATE OF MANUFACTURE AND PRODUCTION TEST

I. MANUFACTURE

Manufacturer's name and address ....

Purchaser's name and address .... Name of the purchaser ....

Inspecting authority & address..............................

Type of vessel (horizontal or vertical) .... Vessel No. (Manufacturer's Serial No.) .... Year built..............................

No. of shells & drums.............................. Dia (inside or outside).............................. Overall length or height of vessel..............................

Identification marks or stamps.............................. Drawing No. ....

Brief description of vessel (Intended use or application, duty, etc) ....

Working pressure.............................. Design pressure.............................. Hydraulic test pressure ....
Hydraulic test Witnessed by ....

Working temperature.............................. Design temperature..............................

Joint efficiency factor : Long seam.............................. Girth or circumferential seam ....

Shell plates (Thickness).............................. Type of seam : Longitudinal (No. & Type).............................. Girth or circumferential (No. & Type)..............................

Materials of construction (material specification)..............................

Tensile strength.............................. Elongation.............................. Chemical composition, if any..............................

Heat treatment (preheat, stress relief or normalizing) .... Preheat temperature.............................. Details of heat treatment if any (to be attached as an enclosure) ....

Whether steel maker's certificate of manufacture & results of test attached..............................

Details of shop inspection (Report of manufacturer's inspecting authority).............................. Calibration and dimensional Check on vessel ....

Details of repairs carried out, if any, to seams during construction..............................

Details of radiography and other non-destructive test reports (mention report No. & date)..............................

Whether welding procedure qualified.............................. Whether welder's performance certified..............................

II. PRODUCTION TESTS (MECH)

1. REDUCED-SECTION TENSILE TEST

Specimen No.	Dimensions, mm Width	Dimensions, mm Thickness	Area mm^2	Gauge Length mm	Ultimate Load, kgf	Tensile Strength kgf/mm^2	Yield Point	Elongation percent	Character of Failure and Location	Remarks
......	......	......	......	......	......	......	......	......	......	......

2. ALL-WELD METAL TENSILE TEST

Specimen No.	Dimensions, mm Diameter	Area mm^2	Gauge Length mm	Ultimate Load, kgf	Tensile Strength kgf/mm^2	Yield Point	Elongation percent	Character of Failure and Location	Remarks
......	......	......	......	......	......	......	......	......	......

3. GUIDED FACE-BEND TEST (TRANSVERSE)

Specimen No.	Angle of Bend	Former Radius mm	Thickness of Specimen mm	Description, Location, Nature and Size of any Crack or Tearing of Specimen	Remarks
....	....	....	....	....	....

4. GUIDED ROOT-BEND TEST (TRANSVERSE)

Specimen No.	Angle of Bend	Former Radius mm	Thickness of Specimen mm	Description, Location, Nature and Size of any Crack or Tearing of Specimen	Remarks
....	....	....	....	....	....

5. GUIDED SIDE-BEND TEST (TRANSVERSE)

Specimen No.	Angle of Bend	Former Radius mm	Thickness of Specimen mm	Description, Location, Nature and Size of any Crack or Tearing of Specimen	Remarks
....	....	....	....	....	....

6. NICK-BREAK TEST

Specimen No.	Type/Depth Nick	Specimen Thickness mm	Description, Appearance of Fracture	Result
....	....	....	....	....

7. IMPACT OR NOTCHED BAR TEST

Specimen No.	Type/Depth of Notch	Specimen	Test Temperature °C	Impact Values kgf.m/m²	Appearance of Fracture	Remarks
....	....	....	....	....	....	....

8. MACRO EXAMINATION & HARDNESS TEST

Specimen	Type of Etchant or Preparation	Observation	Remarks
....	....	....	....

Certified that the particulars entered in this report are correct. The workmanship, inspection and tests have been carried out in accordance with the provision of IS : 2825-1969.

Countersigned by

(Signature & Designation)

Inspecting Authority/Purchaser's Authorized Representative

Date

Office Seal

Signature of manufacturer

Designation

Date

APPENDIX N*

(*Clause* 0.5)

INSPECTION, REPAIR AND ALLOWABLE WORKING PRESSURE FOR VESSELS IN SERVICE

N-1. SCOPE

N-1.1 This appendix deals with inspection, repair and allowable working pressures in vessels in service. The requirements of this appendix are only recommendatory.

N-2. TERMINOLOGY

N-2.0 For the purpose of this appendix, the following definitions shall apply.

N-2.1 Service Inspector — A person who by reason of his training and experience is competent to undertake the inspection of pressure vessels.

N-2.2 Inspection — Thorough scrutiny of the vessel by service inspector externally and internally, wherever possible; it may be only visual examination or it may be supplemented by touch or other sensory action or by means of tests.

N-3. INSPECTION

N-3.0 Vessels constructed in accordance with this code shall be permitted to operate under the conditions for which they were designed for a period determined in accordance with this appendix and where this and each subsequent period is elapsed the vessel should be inspected as in the following paragraphs and the allowable conditions for service and the next period of inspection established.

If the conditions of operation are changed, the allowable working pressures, or temperature or both and the next period of inspection should be established by these new conditions.

If both the ownership and location of the vessel are changed, the vessel shall be inspected as required in this appendix and the allowable conditions of service and the next period of inspection established.

N-3.1 Periodicity of Inspection

N-3.1.1 The maximum period between inspections should not exceed one-half of the estimated remaining safe operating life of the vessel; which requires deduction of 50 percent of the remaining corrosion allowance from the last measured minimum thickness in computing the allowable working pressure.

In cases where part or all of the vessel has a protective lining, then maximum period between inspections should be determined from a consideration of any previous record for the lining during similar operations and in consideration of the following:

a) The corrosion allowance on the protected parent metal if there is any likelihood of the lining failing, and

b) The remaining corrosion allowance on the parent metal if it were not protected by lining.

N-3.1.2 *Dependence on Corrosion* — In addition to the requirements of **N-3.1.1**, the period between inspection shall be subject to the following requirements:

Sl No.	*Corrosion Rate Percent of Minimum Wall Thickness Under the Operating Conditions*		*Period of Inspection not to Exceed*
			Years
a)	—	>10	1
b)	$\geqslant 8$	$\ngtr 10$	2
c)	$\geqslant 6$	$\ngtr 8$	3
d)	$\geqslant 4$	$\ngtr 6$	4
e)	—	$\ngtr 4$	5

N-3.1.3 *Safety and Pressure Relief Devices* — The safety valve equipment and other pressure relief devices, such as rupture dicks, safety valves, etc, should be inspected and tested as frequently as necessary but at least once in a year.

N-3.1.4 In addition to the thorough inspection as required under **N-3.1.1**, **N-3.1.2** and **N-3.1.3** all vessels shall be given a visual external examination at least once in a period of six months to determine the condition of supports, insulation and the general conditions of the vessel.

N-3.1.5 *Special Cases*

N-3.1.5.1 *Vessels not in continuous service* — The periods for inspection referred to above assume that the vessel is operating with normal shut-down intervals. If the vessel is out of service for an extended interval, the effect of this change in condition may be considered in revising the data for the next inspection, which was established and reported at the time of the previous inspection. If the vessel is out of service for a continuous period of one year or more, it should be given an inspection before it is again placed in service.

N-3.2 Inspection for Corrosion

N-3.2.0 The minimum thickness and the maximum corrosion rate for any part of the vessel should be determined at each inspection specified

*See also Section 31 of the Factories Act, 1948 and the Rules made thereunder.

under **N-3.1** by any suitable method or as follows.

N-3.2.1 The depth of corrosion in vessels subjected to corrosive service may best be determined by gauging from protected surfaces within the vessels, when such surfaces are available. These protected services may be obtained by welding corrosion-resistant strips or buttons to the corrosion susceptible surfaces of the vessel and removing the strips during inspection.

When strips or buttons cannot be used because of electrolytic action or other reasons, small holes may be drilled from the corrosion susceptible surface at suitable intervals to a depth equal to the metal thickness allowed for corrosion, and these holes plugged with protective material that can be readily removed to determine from time to time the loss in metal thickness as measured from the bottom of these holes.

N-3.2.2 When the depth of corrosion cannot be readily determined otherwise, holes may be drilled in portion of the metal where corrosion is expected to be the maximum and the thickness obtained by taking thickness gauge measurements to the next 0·8 mm below the gauge reading or any suitable method that will not affect the safety of the vessel may be used provided it will assess the minimum thickness accurate to within 0·8 mm.

N-3.2.3 Where the area in the vessel is excessively corroded, the average of the least thickness within that area may be considered as the thickness of the metal. This thickness should be used as a basis for computing the allowable working pressure and for determining the corrosion rate at that location.

N-3.2.4 Isolated corrosion pits may be ignored provided their depth is not more than 50 percent of the thickness of the vessel wall and the total area of the pits does not exceed 45 cm^2 within any 20 cm diameter circle.

N-3.2.5 *Correction of Corrosion Rate* — If on measuring the wall thickness at any inspection, it is found that an inaccurate rate of corrosion has been assumed, the rate to be used for the next period should be suitably modified to conform to the actual rate found.

N-3.3 Inspection for Defects

N-3.3.0 The parts of the pressure vessel which need to be carefully inspected depend on the type of vessel and the operating conditions to which it is subjected. The inspector should suitably modify the requirements given under this paragraph to meet the special needs peculiar to local conditions. All surfaces before inspection should be thoroughly cleaned.

N-3.3.1 *Shells* — All surfaces of the shell plate shall be carefully examined for cracks, laminations, and other injurious defects.

N-3.3.2 *End Plates* — The inner surface of the knuckle radius of domed ends, etc, when not protected by lining should be carefully examined for cracks or other signs of distress. If the ends show evidence of distortion, corrosion resistance lining should be removed and the inner surface of the knuckle carefully inspected and the head shape checked against the design.

N-3.3.3 *Joints* — The inner and outer surfaces of the welded joints should be carefully inspected for possible cracks by magnetic particle inspection or any other suitable method. Corrosion-resistant lining or outside insulation which appear to be sound need not be removed to inspect the joints unless unsafe conditions are suspected.

N-3.3.4 *Nozzles and Openings* — Nozzles and their attachments should be examined for distortion and for cracks in the welds and particular attention given to welds in the reinforcement plates. Riveted or bolted nozzles should be examined for corrosion of heads and other conditions which may affect tightness. Threaded connections should be examined for appearance and if they seem deteriorated, the threaded nipple should be removed to permit check on the number of threads that are defective. If careful inspection shows no unsafe condition, sound corrosion-resistant lining used need not be removed.

N-3.3.5 *Linings*

N-3.3.5.1 In vessels provided with corrosion-resistant linings, the lining should be examined to check that no cracks exist. If there is evidence of cracks or other openings in the lining, portions should be removed to check if there is corrosion taking place in the shell behind the lining.

N-3.3.5.2 For vessels that are used in corrosive service in which deposits, such as coke cinder, are formed or permitted to remain, examination of the plate at critical points should be made to see that no corrosion takes place behind the deposit.

N-3.4 Check of Dimensions — The vessels should be examined for visible indication of distortion and if any such distortion is suspected, the overall dimensions of the vessel should be checked.

N-3.5 Safety and Pressure Relief Devices — The safety valves and other protective devices, such as rupture discs and vacuum valves, where used, should be checked to see that they are in proper condition. This inspection in the case of valve will normally include a check on the required operation at the set pressure, a check that the proper spring is installed for the service, and that the discharge header and outlets are free of loose corrosive products or other stoppage.

N-3.6 Temperature Measuring Devices — Temperature measuring devices where used for determining metal temperature in excess of 450°C should be checked for accuracy and general condition.

N-3.7 Allowable Operation Based on Inspection Data

N-3.7.1 Defects or damage discovered during inspection should be repaired in accordance with the requirements of item or should constitute the

basis for reducing the allowable working pressure or as a final resort for retiring the vessel from service.

N-3.7.2 *Allowable Working Pressure* — The allowable working pressure for a vessel in operation should be computed with the proper formulae in this code using the dimensions actually determined for thickness '*t*' and twice the estimated corrosion allowance before the next inspection and making suitable allowances for the other loadings specified in this code.

The allowable working pressure of vessels, designed or built with one or more openings, for which the closures are auxiliary equipment not part of the pressure vessels, may be determined only after due consideration of the auxiliary equipment to be used as closures.

N-3.8 Record of Inspection

N-3.8.1 A permanent and progressive record should be maintained for each pressure vessel manufactured in accordance with this code given in the following information:

a) Serial number of the vessel;
b) Thickness at critical points at each inspection;
c) Maximum metal temperature at critical points;
d) Computed permissible working pressure at the time of next inspection;
e) Hydrostatic test pressure or its equivalent, if so tested; and
f) Date of next inspection.

N-4. COMPUTATION OF PROBABLE RATE OF CORROSION

N-4.0 For new vessels and in case of vessels for which service conditions are being changed, the probable rate of corrosion for which the remaining wall thickness at the time of inspection can be estimated should be computed by one of the methods given in the following clauses.

N-4.1 The corrosion rate established by accurate data collected by the owner or user of vessels in the same or similar service.

N-4.2 Where accurate measurements are not available, the probable rate of corrosion estimated from the inspector's knowledge and experience of vessels in similar service.

N-4.3 By thickness measurements made after 1 000 hours in use.

N-4.4 One normal run of longer duration than this and subsequent sets of thickness measurements after additional similar intervals. If the probable corrosion is determined by this method the rate found while the surface layer, was present, should not be applied after the surface layer has disappeared.

N-5. REPAIRS, ALTERATIONS, ADDITIONS

N-5.0 No repairs, additions or alterations to vessels covered by this code should be undertaken until the proposed repair and its method of execution has been approved by the inspector. Repairs should be of the highest quality of workmanship executed in a manner and by practices acceptable

A typical form for keeping the records is given below:

Record of Service Inspections of Vessel No. ....

Owner's Serial No. ....

Manufacturer.................................. Manufacturer's Sl No. .... Year built.................................

Design pressure........................ Design temperature..................... Original hydrostatic test pressure..................

Date of last inspection...

Owner.............................. Location.............................. Service........................... Date...........................

Owner.............................. Location.............................. Service........................... Date...........................

Owner.............................. Location.............................. Service........................... Date...........................

Owner.............................. Location.............................. Service........................... Date...........................

Date of inspection	Thickness at critical points*	Maximum metal temperature at critical points	Maximum corrosion allowance remaining	Calculated allowable working pressure	Date of next inspection	Signature of Inspector

*The position of these critical points shall be marked up on a sketch or a copy of manufacturing drawing to be attached to this record.

under the provisions of this code and under proper supervision. Complete records of repairs, alterations and additions shall be made and maintained for future reference.

All welding should be done by qualified welding operators who have demonstrated their ability to meet all requirements of the welding and under conditions that will prevent excessive stress developing in the vessel. Where welding has been done on vessels that have been stress-relieved in accordance with the provision of this code, the parts affected should be stress-relieved wherever it is required by this code. If stress-relieving is not required and is not done, the joint efficiency should conform to that permitted for a class 3 vessel.

N-5.1 Welded Joints and Plates — Repairs to welded joints, cracks and to minor plate defects may be made after chipping out a U- or V-shaped groove to the full depth and length of the crack by filling this groove with weld metal.

N-5.2 Corrosion Pits — Isolated corrosion pits may be chipped out to sound metal and filled up by weld metal.

N-5.3 Corroded or Distorted Flange Faces — Corroded flange faces should thoroughly be cleaned and built up with weld metal and remachined in place to a thickness not less than that of the original flange. Corroded flanges may also be remachined in place without building up with weld metal, provided that all metal removed in the process comes from a raised face and does not reduce the thickness of the main portion of the flange.

N-5.3.1 *Warped Flanges* — Warped flanges which cannot be remachined or flanges which have become distorted due to excessive tightening of the flange bolts should be replaced with new flanges welded on in accordance with the requirements of this code.

N-5.4 Cracks at Tapped Opening — Repairs to cracks at a tapped opening merely by chipping out, welding or re-tapping is not recommended.

A fully reinforced flange nozzle may be installed, or if a tapped connection is required it may be provided by welding in a section of seamless tubing for the full depth of the plate of length at least twice the plate thickness and at least 25 mm in diameter larger than the tapped opening, or by other adequate reinforcing.

N-5.5 Application of Patches of Vessels by Welding

N-5.5.1 Patches to be welded to vessel walls should meet the same specifications as the plate to be repaired. All details of the welding procedure should conform to those followed in welding the main joint of the vessel. If the patch is to be inlaid in a seamless section, a stress-relieved double welded butt joint should be made. Care should be exercised to prevent cracking.

If the patch is to be applied as an overlay, welding should be performed in the same manner as for a reinforcing plate around an opening and the proportion of the patch being determined in accordance with this code. The application of patch plates to both the outside and inside of the vessel wall is preferred to a single overlaid plate. Overlaid patches attached by welding should be limited to wall thickness not over 16 mm.

N-5.5.2 Alterations or new connections that may be installed on vessels shall conform to the requirements of this code as regards the design, location and method attachment.

N-6. HYDROSTATIC TEST

N-6.1 Where it is not possible to inspect the interior of the vessels as required under **3**, it should be subjected to a hydrostatic test or equivalent.

N-6.2 A vessel which has undergone repairs or alterations and which in the opinion of the inspector is of sufficient magnitude to affect its safety should be given hydrostatic test or equivalent in accordance with the provisions of this code.

AMENDMENT NO. 1 SEPTEMBER 1977

TO

IS : 2825-1969 CODE FOR UNFIRED PRESSURE VESSELS

Alterations

[*Page* 18, *clause* **3.4.2** (c)] — Substitute 'Torispherical' *for* 'Dished and flanged'.

[*Page* 19, *caption of Fig.* 3.3 (C)] — Substitute 'Torispherical Ends' *for* 'Dished and Flanged Ends'.

(*Page* 21, *clause* **3.4.5**, *Note* 2, *line* 3) — Substitute '$\frac{d}{\sqrt{t.D_0}}$' *for* '$d\sqrt{t.D_0}$' at both the places.

(*Page* 24, *clause* **3.6.1.1**, *definition of symbol D*) — Substitute the following for the existing definition:

'D = diameter or short span measured as in Table 3.7, in mm;'.

[*Page* 33, *clause* **3.8.5.2** (b) (3), *definition of symbol H_2*, *line* 6] — Substitute '$\sqrt{d(t-2c)}$' *for* '$\sqrt{d(t-2C)}$'.

(*Page* 43, *clause* **4.4**, *definition of symbol A*) — Substitute 'mm' *for* 'mm^2'.

(*Page* 43, *clause* **4.4**, *definition of symbol C_F*)— Substitute the following for the existing matter:

'C_F = bolt pitch correction factor

$$= \sqrt{\frac{\text{bolt spacing}}{2\,(\text{bolt diameter}) + t}}$$

The value of C_F shall be, however, not less than 1.'

(*Page* 44, *clause* **4.4**) — After the definition of symbol F_L and before the sign of equality '=', insert the notation 'f'.

(*Page* 44, *clause* **4.4**, *definition of symbol G*, *line* 7) — Substitute '$b_0 > 6{\cdot}3$ mm' *for* '$b > 6{\cdot}3$ mm'.

[*Page* 46, *Fig.* 4.1 (B)] — Substitute 'h_t' *for* 'h_r'.

[*Page* 46, *Fig.* 4.1 (E), (F), (G)]

a) Add the following caption above the figures:
'INTEGRAL-TYPE FLANGES'

b) Substitute 'h_t' *for* 'h_r' and 'H_T' *for* 'H_r'.

Gr 1

(*Page* 47, *Fig.* 4.2) — Substitute ' $b_o \leqslant 6 \cdot 3$ mm ' *for* ' $b_o = 6 \cdot 3$ mm '.

(*Pages* 54 *and* 55, *Table* 4.2, *col* I *and* II) — Substitute ' *W* ' *for* ' *w* ' and ' *T* ' *for* ' 25 *T* '.

(*Page* 67, *clause* **6.4.2.3**, *last sentence*) — Substitute the following for the existing sentence:

' When plates are flame-cut, the edges should be examined, as far as possible, immediately after this operation. '

(*Page* 72, *clause* **6.6.6**, *second sentence*) — Substitute the following for the existing sentence:

' Unless otherwise specified the out of straightness of the shell shall not exceed 0·3 percent of the total cylindrical length in any 5 m length. '

(*Page* 75, *clause* **6.12.2.5**, *line* 8) — Substitute ' physical properties ' *for* ' yield point '.

(*Page* 78, *clause* **6.12.4.2**, *line* 5) — Substitute ' weld ' *for* ' shell '.

[*Page* 103, *clause* **8.7.1.1** (c), *line* 4] — Substitute ' 19 mm ' *for* ' 20 mm '.

(*Page* 167, *Table* C.5, *last row*) — Substitute ' $\frac{b_1}{2}$ ' *for* ' $\frac{b}{2}$ '.

(*Page* 167, *clause* **C-4.3.2.4**, *definition of* f_n) — Substitute the following for the existing matter:

' $f_n = pD_o \, C/2t \times 100$ in which C is the shape factor from Fig. 3.7. '

[*Page* 168, *equations* (C.19) *and* (C.20)] — Substitute ' I ' *for* ' l ' at both the places.

(*Page* 181, *clause* **F-4.1**, *definition of symbol* I_s , *line* 2) — Substitute ' cm^4 ' *for* ' mm^4 '.

(*Pages* 115, 116 *and* 117, *Table* A.1) — Substitute the following for the existing Table:

TABLE A.1 ALLOWABLE STRESS VALUES FOR CARBON AND LOW ALLOY STEEL IN TENSION

Material Specification	Grade or Designation	Category of Chemical Composition (*see* Table B.1)	Mechanical Properties: Tensile Strength *Min* kgf/mm² R_{20}	Mechanical Properties: Yield Stress *Min* kgf/mm² E_{20}	Mechanical Properties: Percentage Elongation *Min* on Gauge Length $= 5{\cdot}65\sqrt{S_o}$	Allowable Stress Values in kgf/mm² at Design Temperature, °C: Up to 50	Up to 100	Up to 150	Up to 200	Up to 250	Up to 300	Up to 350	Up to 375	Up to 400	Up to 425	Up to 450	Up to 475	Up to 500	Up to 525	Up to 550	Up to 575	Up to 600
						Plates																
IS : 2002-1962	I	A	37	$0{\cdot}55R_{20}$	26	12·3	12·3	11·5	10·4	9·5	8·7	7·8	7·5	7·2	5·9	4·3	3·6	—	—	—	—	—
IS : 2002-1962	2A	A	42	$0{\cdot}50R_{20}$	25	14·0	12·9	11·9	10·8	9·8	9·0	8·1	7·7	7·4	5·9	4·3	3·6	—	—	—	—	—
IS : 2002-1962	2B	A	52	$0{\cdot}50R_{20}$	20	17·3	15·9	14·7	13·3	12·1	11·1	10·0	9·5	8·3	5·9	4·3	3·6	—	—	—	—	—
IS : 2041-1962	20Mo55	B	48	28	20	16·0	16·0	16·0	15·3	14·3	13·2	12·3	11·9	11·5	11·2	10·8	7·7	5·6	3·7	—	—	—
IS : 2041-1962	20Mn2	A	52	30	20	17·3	17·3	17·0	15·4	14·0	12·8	11·6	11·0	8·3	5·9	4·3	3·6	—	—	—	—	—
IS : 1570-1961	15Cr90Mo55	D	50	30	20	16·6	16·6	16·6	16·6	16·0	15·2	14·4	13·8	13·4	13·0	12·6	11·7	8·6	5·8	3·5	—	—
IS : 1570-1961	C15Mn75	A	42	23	25	14·0	14·0	13·0	11·8	10·7	9·8	8·9	8·4	8·1	5·9	4·3	3·6	—	—	—	—	—
						Forgings																
IS : 2004-1962	Class I	A	37	$0{\cdot}50R_{20}$	—	12·3	11·3	10·4	9·5	8·6	7·9	7·1	6·8	6·5	5·9	4·3	3·6	—	—	—	—	—
IS : 2004-1962	Class 2	A	44	$0{\cdot}50R_{20}$	15	14·6	13·4	12·4	11·3	10·2	9·3	8·5	8·0	7·7	5·9	4·3	3·6	—	—	—	—	—
IS : 2004-1962	Class 3	A	50	$0{\cdot}50R_{20}$	21	16·6	15·3	14·1	12·8	11·7	10·7	9·6	9·1	8·3	5·9	4·3	3·6	—	—	—	—	—
IS : 2004-1962	Class 4	A	63	$0{\cdot}50R_{20}$	15	21·0	19·3	17·8	16·1	14·7	13·4	12·2	11·5	8·3	5.9	4·3	3·6	—	—	—	—	—
IS : 1570-1961	20Mo55	B	48	28	20	16·0	16·0	16·0	15·3	14·3	13·2	12·3	11·9	11·5	11·2	10·8	7·7	5·6	3·7	—	—	—
IS : 2611-1964	15Cr90Mo55	D	50	30	20	16·6	16·6	16·6	16·6	16·0	15·2	14·4	13·8	13·4	13·0	12·6	11·7	8·6	5·8	3·5	—	—
IS : 1570-1961	10Cr2Mo1	E	50	32	20	16·6	16·6	16·6	16·6	16·6	16·6	16·4	16·1	15·8	15·3	14·9	12·7	9·6	7·0	4·9	3·2	2·3
						Tubes, Pipes																
IS : 3609-1966	1%Cr - ½%Mo Tube Normalized and Tempered	D	44	24	$950/R_{20}$	14·6	14·6	14·2	13·6	12·8	12·1	11·5	11·1	10·7	10·4	10·0	9·7	8·6	5·8	3·5	—	—
IS : 3609-1966	2¼Cr - 1%Mo Tube Normalized and Tempered	E	49	25	$950/R_{20}$	16·3	15·6	15·0	14·5	14·0	13·5	12·8	12·6	12·3	12·0	11·6	11·3	9·6	7·0	4·9	—	—
IS : 1570-1961	20Mo55	B	46	25	$950/R_{20}$	15·3	15·3	14·6	13·6	12·8	11·8	11·0	10·6	10·3	10·0	9·6	7·7	5·6	3·7	—	—	—
IS : 1914-1961	32 kgf/mm², *Min* Tensile Strength	A	32	$0{\cdot}50R_{20}$	$950/R_{20}$	10·6	9·8	9·0	8·2	7·4	6·8	6·2	5·8	5·6	5·0	4·3	3·6	—	—	—	—	—
IS : 1914-1961	43 kgf/mm², *Min* Tensile Strength	A	43	$0{\cdot}50R_{20}$	$950/R_{20}$	14·3	13·1	12·2	11·0	10·0	9·2	8·3	7·9	7·6	5·9	4·3	3·6	—	—	—	—	—
IS : 2416-1963	32 kgf/mm², *Min* Tensile Strength	A	32	$0{\cdot}50R_{20}$	$950/R_{20}$	10·6	9·8	9·0	8·2	7·4	6·8	6·2	5·8	5·6	5·0	4·3	3·6	—	—	—	—	—

(*Continued*)

TABLE A.1 ALLOWABLE STRESS VALUES FOR CARBON AND LOW ALLOY STEEL IN TENSION — *Contd*

Material Specification	Grade or Designation	Category of Chemical Compo-sition (*see* Table B.1)	Mechanical Properties: Tensile Strength *Min* kgf/mm² R_{20}	Mechanical Properties: Yield Stress *Min* kgf/mm² E_{20}	Mechanical Properties: Percentage Elongation *Min* on Gauge Length $= 5{\cdot}65\sqrt{S_0}$	Allowable Stress Values in kgf/mm² at Design Temperature, °C: Up to 50	Up to 100	Up to 150	Up to 200	Up to 250	Up to 300	Up to 350	Up to 375	Up to 400	Up to 425	Up to 450	Up to 475	Up to 500	Up to 525	Up to 550	Up to 575	Up to 600
IS : 1978-1961	St 18	A	31·6	17·6	—	10·5	10·5	9·9	9·0	8·2	7·5	6·7	6·4	6·2	5·9	4·3	3·6	—	—	—	—	—
	St 20	A	33·7	19·7	—	11·2	11·2	11·2	10·1	9·2	8·4	7·6	7·2	6·9	5·9	4·3	3·6	—	—	—	—	—
	St 21	A	33·7	21·1	—	11·2	11·2	11·2	10·8	9·8	9·0	8·1	7·7	7·4	5·9	4·3	3·6	—	—	—	—	—
	St 25	A	42·2	24·6	—	14·0	14·0	13·9	12·6	11·5	10·5	9·5	9·0	8·3	5·9	4·3	3·6	—	—	—	—	—
IS : 1979-1961	St 30	A	42·2	29·5	—	14·0	14·0	14·0	14·0	13·8	12·6	11·5	10·8	8·3	5·9	4·3	3·6	—	—	—	—	—
	St 32	A	44·3	32·3	—	14·7	14·7	14·7	14·7	14·7	13·8	12·5	11·8	8·3	5·9	4·3	3·6	—	—	—	—	—
	St 37	A	46·4	36·6	—	15·4	15·4	15·4	15·4	15·4	15·4	14·1	13·4	8·3	5·9	4·3	3·6	—	—	—	—	—
Castings*																						
IS : 3038-1965	Grade 1	A	55	35	17	13·7	13·7	13·7	13·5	12·2	11·2	10·1	9·6	6·2	4·4	3·2	2·7	—	—	—	—	—
	Grade 2	B	47	25	17	11·7	11·6	11·0	10·2	9·6	8·8	8·2	8·0	7·7	7·5	7·2	5·8	4·2	2·8	—	—	—
	Grade 3	C	52	31	15	13·0	13·0	13·0	12·7	11·9	11·0	10·2	9·9	9·6	9·3	8·4	5·8	4·2	2·8	—	—	—
	Grade 4	D	49	28	17	12·2	12·2	12·2	11·9	11·2	10·6	10·1	9·7	9·3	9·1	8·8	8·5	6·5	4·4	2·6	—	—
	Grade 5	E	52	31	17	13·0	13·0	13·0	13·0	13·0	12·5	11·9	11·7	11·4	11·1	10·8	9·5	7·2	5·3	3·7	2·4	—
	Grade 6	F	63	43	15	15·7	15·7	15·7	15·7	15·7	15·7	15·5	14·9	14·4	14·0	13·5	6·7	4·9	3·5	2·6	1·7	0·9
IS : 2856-1964	C Sw-C20	A	42	21	20	10·5	9·6	8·9	8·0	7·3	6·7	6·1	5·7	5·5	4·4	3·2	2·7	1·6	—	—	—	—
	C Sw-C25	A	49	25	18	12·2	11·5	10·6	9·6	8·7	8·0	7·2	6·8	6·2	4·4	3·2	2·7	1·6	—	—	—	—
Rivet and Stay Bars																						
IS : 1990-1962		A	37	0·55R_{20}	26	12·3	12·3	11·5	10·4	8·6	7·9	7·1	6·8	6·5	5·9	4·3	3·6	—	—	—	—	—
		A	42	0·55R_{20}	23	14·0	14·0	13·1	11·8	9·8	9·0	8·1	7·9	7·4	5·9	4·3	3·6	—	—	—	—	—
Sections, Plates, Bars																						
IS : 226-1962	St 42-S	A	42	24	23	14·0	14·0	13·6	12·3	9·8	9·0	8·1	—	—	—	—	—	—	—	—	—	—
IS : 961-1962	St 55 HTW	A	50	29	20	16·6	16·6	16·4	14·8	11·7	10·7	9·6	—	—	—	—	—	—	—	—	—	—
IS : 2062-1962	St 42-W	A	42	23	23	14·0	14·0	13·0	11·8	9·8	9·0	8·1	—	—	—	—	—	—	—	—	—	—
IS : 3039-1965	Grade A	A	—	—	—	14·0	14·0	13·0	11·8	9·8	9·0	8·1	—	—	—	—	—	—	—	—	—	—
	Grade D	A	—	—	—	14·6	16·6	16·4	14·8	11·7	10·7	9·6	—	—	—	—	—	—	—	—	—	—
IS : 3503-1966	Grade 1	A	37	0·50R_{20}	26	12·3	11·3	10·4	9·5	8·6	7·9	7·1	6·8	6·5	5·9	4·3	3·6	—	—	—	—	—
	Grade 2	A	42	0·50R_{20}	25	14·0	12·9	11·9	10·8	9·8	9·0	8·1	7·7	7·4	5·9	4·3	3·6	—	—	—	—	—
	Grade 3	A	44	0·50R_{20}	23	14·6	13·4	12·4	11·3	10·2	9·3	8·5	8·0	7·7	5·9	4·3	3·6	—	—	—	—	—
	Grade 4	A	47	0·50R_{20}	22	15·6	14·4	13·3	12·1	11·0	10·0	9·1	8·3	8·3	5·9	4·3	3·6	—	—	—	—	—
	Grade 5	A	50	0·50R_{20}	21	16·6	15·3	14·1	12·8	11·7	10·7	9·6	9·1	8·3	5·9	4·3	3·6	—	—	—	—	—
IS : 3945-1966	Grade A-N	A	44	24	23	14·6	14·6	13·6	12·3	9·8	9·0	8·1	—	—	—	—	—	—	—	—	—	—
	Grade B-N	A	50	28·5	20	16·6	16·6	16·1	14·6	11·7	10·7	9·6	—	—	—	—	—	—	—	—	—	—

*These values have been based on a quality factor of 0·75. For additional inspection as detailed in Note to Table 2.1, a quality factor of 0·9 shall be used and the above stress values increased proportionally.

Printed at Kay Kay Printers, Delhi

AMENDMENT NO. 2 OCTOBER 1978

TO

IS : 2825 - 1969 CODE FOR UNFIRED PRESSURE VESSELS

Alterations

Sl No.

1. (*Page* 6, *clause* **1.3.1.1**, *para* 2) — Substitute the following for the existing paragraph:

 'All welded joints of Class 1 vessels shall meet the requirements stipulated in col 3 of Table 1.1. All butt joints shall be fully radiographed. Circumferential butt joints in nozzles, branches and sumps not exceeding 170 mm outside diameter or 19 mm wall thickness need not be radiographed (*see* **8.7.1.1**) except for vessels that are to contain lethal* or toxic substances.'

2. (*Page* 6, *clause* **1.3.1.1**, *paras* 4 *and* 5) — Substitute the following for the existing paragraphs:

 'a) *Category A* — Longitudinal welded joints within the main shell, communicating chambers†, transitions in diameter, or nozzles; any welded joint within a sphere, within a formed or flat head, or within the side plates of a flat sided vessel; circumferential welded joints connecting hemispherical heads to main shells, to transitions in diameters, to nozzles, or to communicating chambers†.

 b) *Category B* — Circumferential welded joints within the main shell, communicating chambers†, nozzles or transitions in diameter including joints between the transition and a cylinder at either the large or small end; circumferential welded joints connecting formed heads other than hemispherical to main shells, to transitions in diameter, to nozzles, or to communicating chambers†.'

3. [*Page* 8, *Table* 1.1, *against Sl No.* 3(b), *col* (5), (6) *and* (7)] — Substitute the following for the existing matter in each of these columns:

 '**Maximum thickness 16 mm before corrosion allowance is added, and 18 mm after adding corrosion allowance**'

4. (*Page* 11, *clause* **2.2.4**) — Substitute the following for the existing clause:

 '**2.2.4** *Bearing Stress* — The maximum permissible bearing stress shall not exceed the allowable stress value.'

Sl No.

5. [*Page* 11, *clause* **3.1.3.1**(c)] — Substitute the following for the existing text:

 'c) Wind loading in combination with other loadings (*see* **C-4.1.3**),

 d) Seismic loads (*see* IS : 1893-1975*).'

6. (*Page* 11, *foot-note*) — Add the following new foot-note:

 '*Criteria for earthquake resistant design of structures (*second revision*).'

7. (*Page* 12, *clause* **3.2.2**) — Add the following note after the clause:

 'NOTE — All calculations in this Code are in corroded condition unless otherwise specified.'

8. (*Page* 12, *clause* **3.2.3**, *para* 2) — Add the following at the end of the paragraph:

 'In such cases tell-tale holes, suitably disposed, shall be provided on the vessel wall so that easy detection of leakage in welds in lining is made possible. They shall have a depth not less than 80 percent of the thickness required for a seamless shell of like dimensions or they may extend to the lining.'

9. (*Page* 13, *clause* **3.3.2.1**, *definition of symbol E*) — Delete the words '*see* Tables 3.1, 3.2, 3.3 and 3.4)'.

10. (*Page* 13, *clause* **3.3.2.4**, *definition of symbols E*, E_a) — Delete the words '(*see* Tables 3.1, 3.2, 3.3 and 3.4)'.

11. (*Page* 14, *Tables* 3.1, 3.2, 3.3 *and* 3.4) — Delete.

12. (*Page* 15, *clauses* **3.3.3** *and* **3.3.3.1**)— Substitute the following for the existing clauses:

 '**3.3.3** *Shells Subjected to Extend Pressure*

 3.3.3.1 The thickness of shells subjected to external pressure shall be calculated by the method given in Appendix F.'

13. [*Page* 15, *clauses* **3.3.3.2**, **3.3.3.3**, **3.3.3.4**(a) *and* **3.3.3.4**(b)] — Delete these clauses.

14. (*Page* 16, *new clause* **3.3.3.2**) — Add the following new clause **3.3.3.2** at the top of the page:

 '**3.3.3.2** *Stiffening rings* — Stiffening rings are generally used with cylindrical shells subjected to external pressure. They extend around the circumference of the shell and may be located on the inside or the outside of the shell.'

Gr 2

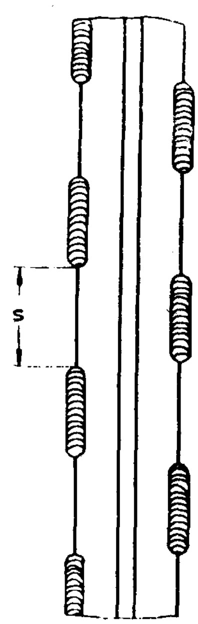
Sl No.

15. [*Page* 16, *clause* **3.3.3.4**(c)] — Renumber the clause as **3.3.3.2**(a).

16. [*Page* 17, *clause* **3.3.3.4**(d)] — Renumber the clause as **3.3.3.2**(b).

17. [*Page* 17, *clause* **3.3.3.4**(d) (1), renumbered as clause **3.3.3.2**(b) (1)] — Substitute the following for the existing text:

'1) the total length of intermittent welding on each side of the stiffening ring shall be not less than one-half the outside circumference of the vessel, for stiffening rings situated on the outside. However, at any location of the stiffening ring there shall be welding between the shell and at least one side of the stiffening ring. The maximum unwelded length *s* on any side shall not exceed 8 times the vessel thickness for external rings and 12 times the vessel thickness for internal rings as shown below:



18. [*Page* 17, *clause* **3.3.3.4**(e)] — Renumber the clause as **3.3.3.3**.

19. (*Page* 17, *clause* **3.3.3.5**) — Renumber the clause as **3.3.3.4**.

20. (*Page* 30, *clause* **3.8.5.1**) — Substitute the following for the existing clause:

'**3.8.5.1** *General* — At all planes through the axis of the opening normal to the vessel surface the cross-sectional area requirements for compensation as calculated below shall be satisfied:

Material in added compensation, or in a branch, should have similar mechanical and physical properties to that in the vessel shell or end. It is recommended that compensation or fittings be made normally from material having an allowable stress not less than 75 percent of the allowable stress for the material in the shell or end. Where material having a lower allowable stress than that of the vessel shell or end is taken as compensation its effective area shall be assumed to be reduced in the ratio of the allowable stresses at the design temperature. No credit shall be taken for the additional strength of material having a higher stress value than that in the shell or end of the vessel.

Material added for compensation shall have approximately same coefficient of thermal expansion (say 85 percent). The thickness of compensating pad shall be limited to the nominal thickness of shell or head as relevant. Any area contributing to compensation shall be attached to shell or head by full penetration welds.'

21. (*Page* 35, *informal table under clause* **3.8.9.1**) — Substitute the following for the existing table:

'*Branch Nominal Size*	*Minimum Thickness*
mm	mm
15	2·4
20	2·4
25	2·7
32	3·1
40	3·1
50	3·6
65	3·9
80	4·7
100	5·4
125	5·4
150	6·2
200	6·9
250	8·0
300	8·0
350	8·8
400	8·8
450	8·8
500	10·0
600	10·0

NOTE — The value given in the table is to be increased by the amount of any required corrosion allowance.'

22. (*Page* 43, *clause* **4.1.3**) — Substitute the following for the existing clause:

'**4.1.3** Hub flanges shall not be made by machining the hub directly from plate materials.'

23. (*Pages* 56, 61, 62, *various sub-clauses of clause* **5**) — Substitute 'device' *for* 'valve' and 'devices' *for* 'valves' wherever it appears.

24. (*Page* 61, *clause* **5.4.1**) — Substitute the following for the existing clause:

Sl No.

'**5.4.1** The total capacity of the relief device or devices fitted to any vessel or system of vessels shall be sufficient to discharge the maximum quantity of fluid, liquid or gas, that can be generated or supplied without permitting a rise in vessel pressure of more than 10 percent above the maximum working pressure when the relief devices are discharging.'

25. (*Page* 65, *clause* **6.2.1.3**) — Substitute the following for the existing clause:

'**6.2.1.3** The weld procedure and welders shall be qualified for the type of welding concerned in conformity with the weld procedure and welders' performance qualifications (*see* **7.1** and **7.2**).'

26. (*Pages* 65 and 66, *clause* **6.3.2**) — Substitute the following for the existing clause:

'**6.3.2** In the design of all details the aim shall be to avoid disturbances in the flow of the lines of force, in particular in constructions subjected to fatigue stresses. Holes and openings shall not be positioned on or in the heat affected zones of welded joints. Where such openings are unavoidable, such holes can be located on circumferential joints provided the main seams are ground flush 75 mm on either side and radiography requirements given in **6.3.2**(a) are met. However openings with added reinforcements should not have the hole cut on the weld seam.

a) The circumferential seam shall be radiographed for a total length of three times the diameter of opening with the centre of whole at mid length. Defects that are completely removed in cutting the hole shall not be considered in judging the acceptability of the weld.'

27. (*Page* 66, *clause* **6.3.2.1**, *second sentence*) — Substitute the following for the existing sentence:

'Joints between cylindrical shells and domed end plates shall not be located in the curved part of the domed end except for hemispherical ends (*see* Table 6.2).'

28. (*Page* 67, *clause* **6.4.2.5**) — Substitute the following for the existing clause:

'**6.4.2.5** Edges which have been flame-cut by hand shall be cut by machining or chipping for a distance not less than 1·5 mm.'

29. [*Page* 71, *clause* **6.6.2**(b)(2), *line* 3] — Substitute '5 mm' *for* '4 mm'.

30. (*Page* 74, *clause* **6.7.16**, *last sentence*) — Substitute the following for the existing sentence:

Sl No.

'In the case of light duty vessels the reinforcement shall be not more than 3 mm for thickness less than 10 mm, and 5 mm for thickness from 10 to 16 mm.'

31. [*Page* 76, *Table* 6.3, *col* (3), *para* 2, *line* 4] — Insert the following between the words 'preheating' and 'for':

'up to a minimum temperature of 150°C'

32. (*Page* 76, *Table* 6.3, *Note* 2, *line* 1) — Substitute '16 mm' *for* '15 mm'.

33. (*Page* 76, *Table* 6.3, *Note* 3, *line* 1) — Substitute '0°C' *for* '−20°C'.

34. [*Page* 81, *clause* **7.1.3.4**(e)] — Substitute the following for the existing clause:

'e) if in gas shielded metal arc (MIG) or tungsten arc (TIG) welding or submerged arc welding a change is made from multiple pass welding per side to single pass welding per side when notch toughness is a requirement.'

35. [*Page* 81, *clause* **7.1.3.4**(h)] — Substitute the following for the existing clause:

'h) if in gas shielded metal arc welding (MIG) or gas shielded tungsten arc welding (TIG) a change is made in the composition of the gas and a change in the electrode from one type to another or from non-consumable electrode to consumable electrode and *vice versa*, or an increase of 25 percent or more or a decrease of 10 percent or more in the rate of flow of shielding gas.'

36. (*Page* 81, *clause* **7.1.3.5**) — Add the following new paragraph after the clause:

'A change from downward to upward or *vice versa* in the progression for any pass of a vertical weld excepting the root pass which will be removed completely while preparing the second side and the cover pass, if notch toughness is a requirement, calls for requalification.'

37. (*Page* 81, *clause* **7.1.4**, *first sentence*) — Add the following new matter after the first sentence:

'However, for temperatures less than 0°C the qualification shall be valid for thickness from 1 to 1·1 times the thickness of test piece.'

38. [*Page* 82, *clause* **7.1.5**(b), *lines* 3 *and* 4] — Delete the words 'one above the other,'

39. [*Page* 82, *clause* **7.1.5**(c), *lines* 3, 4 *and* 5] — Delete the words 'and where the

Sl No.

thickness of the plate permits, one shall be above the other'.

40. [*Page* 82, *clause* **7.1.5**(c)(1), *line* 2] — Substitute '20 mm' *for* '30 mm'.

41. (*Page* 87, *Table* 7.4, *column of maximum range of thickness qualified by test plate corresponding to thickness of test plate 't 20 and over'*)— Substitute '2 *t*' *for* '1·5 *t*'.

42. (*Page* 88, *clause* **7.2.6.4**) — Add the following new clause after this clause:

'**7.2.6.5** Radiography is acceptable in place of mechanical testing for manual metal arc or gas shielded tungsten arc or combination processes.'

43. (*Page* 95, *clause* **8.4.2**, *line* 1) — Delete the words 'in mild or low-alloy steels'.

44. [*Page* 97, *clause* **8.5.1.3**(c), *para* 1, *lines* 3, 4 *and* 5] — Delete the words 'and where the thickness of plate permits, one shall be above the other'.

45. [*Page* 97, *clause* **8.5.1.3**(c), *para* 2 *line* 2] — Substitute '20 mm' *for* '30 mm''

46. [*Page* 97, *clause* **8.5.2.2**(b), *first and second sentence*] — Substitute the following for the existing sentences:

'Two bend test specimens, one for direct and one for reverse bending to be taken transversely to the weld. Where the plate thickness exceeds 20 mm, face bend and root bend tests may be substituted by side bend tests.'

47. (*Page* 100, *clause* **8.5.9.2**, *line* 2) — Substitute '20 mm' *for* '30 mm'.

48. (*Page* 100, *clause* **8.5.9.3**, *lines* 2, 3 *and* 7) — In each of the lines, substitute '20 mm' *for* '30 mm'.

49. (*Page* 101, *clause* **8.5.9.6**) — Add the following new matter in the beginning:

'When specifically asked for by the customer'.

50. [*Page* 103, *clause* **8.6.8.1**(a)]— Add the following new matter at the end:

'For the transverse tensile test if the result exceeds 95 percent of the specified minimum value with fracture occurring in base metal, the test is acceptable.'

51. (*Page* 103, *clause* **8.7.1.2**) —Delete.

52. (*Page* 104, *clause* **8.7.4**, *last sentence*) — Substitute the following for the existing sentence:

'When image quality indicator of the wire-type is used, the smallest diameter wire which can be seen in the radiograph shall have a diameter not greater than 1·5 percent of the weld metal thickness if the weld metal thickness is between 10 and 50 mm inclusive, and not greater than 1·25 percent of the weld metal thickness if the thickness is between 50 mm and 200 mm. In the case of plate type penetrameters, the radiographic examination shall be capable of revealing a difference in metal thickness equal to not more than 2 percent of the thickness of weld under examination.'

53. (*Page* 109, *clause* **8.7.10.2**, *para* 1) — Delete and renumber the second paragraph as '**8.7.10.2**'.

54. (*Page* 110, *clause* **8.7.11**, *first sentence*) — Substitute the following for the existing sentence:

'When special conditions make it expedient, radiography as specified in **8.7.1** and **8.7.2** may be replaced by ultrasonic testing supplemented by dye-penetrant or magnetic particles inspection subject to the previous consent of the inspecting authority and on the condition that such testing methods may be considered to render an equally safe evaluation of the quality of welding work.'

55. (*Page* 178, *clause* **D-6.5**) — Add the following new clause after this clause:

'**D-6.6** All nozzles to shell attachments and nozzles to flange attachments shall be full penetration welds.'

(**EDC 48**)

Printed at Kay Kay Printers, Delhi-

AMENDMENT NO. 3 JULY 1979
TO
IS : 2825-1969 CODE FOR UNFIRED PRESSURE VESSELS

Alterations

Sl No.

1. (*Page* 8, *Table* 1.1, *Sl No.* 4, *col* 2) — Substitute 'Type of joints* ' *for* 'Type of joints'.

2. (*Page* 8) — Add the following foot-note at the end of the page:

'*These joints refer to all categories of Class 1 vessels and categories A and B only of Class 2 and 3 vessels. For categories C and D, details shown in Appendix G or equivalent shall be used, as applicable to the relevant class of the vessel.'

3. (*Page* 8, *Table* 1.1, *Sl No.* 4, *col* 3) — Substitute the following for the existing matter:

'i) Double welded butt joints with full penetration excluding butt joints with metal backing strips which remain in place for categories A, B and C.

ii) Single welded butt joints with backing strip for categories B and C. $J = 0{\cdot}9$ (*see* **6.3.6.1**).

iii) Full penetration weld extending through the entire thickness of vessel wall or nozzle wall for category D.'

4. (*Page* 10, *clause* **2.2.1**) — Add the following matter at the end:

'However, for determining the allowable stress values for **ferrous material** for design temperatures (*see* **1.2.4**) up to and including 400°C, the criteria relating to creep properties (that is, average stress to produce rupture in 100 000 hours and average stress to produce a total creep strain of one percent in 100 000 hours) listed in Table 2.1 shall not be taken into consideration.'

5. [*Page* 31, *clause* **3.8.5.2** (d) (1), *equation* (3.32)] — Substitute the following for the existing equation:

'$A = 0{\cdot}5\ d.\ t_r$ ....(3.32)'

6. (*Page* 71, *clause* **6.4.11**, *first sentence*) — Substitute the following for the existing matter:

'**6.4.11** *Plates Welded Prior to Forming* — Seams in plates may be welded prior to forming provided they meet the specified non-destructive test requirements after forming.'

7. [*Page* 81, *clause* **7.1.3.4** (c)] — Substitute the following for the existing matter:

'c) if in arc welding of single welded butt joints a backing strip is omitted.'

8. [*Page* 83, *clause* **7.1.5** (d)] — Substitute the following for the existing matter:

'd) Three notched bar impact test specimens to be taken transversely to the weld (*see* **8.5.8**) as near as possible to the face side of the last pass of the weld on outer plate surface. If plate thickness exceeds 40 mm, one more set of specimens shall be taken at about midway between centre of thickness and opposite side surface.'

9. [*Page* 97, *clause* **8.5.1.3** (d)] — Substitute the following for the existing matter:

'd) Three notched bar impact test specimens, to be taken transversely to the weld [*see* **7.1.5** (d)].'

10. (*Pages* 195 *to* 223, *Figures in Appendix G*) — Substitute 'permitted' *for* 'recommended' in various figures.

11. (*Appendix G*) — Incorporate a tell-tale hole in the following figures:

'Fig. G.6, Fig. G.7, Fig. G.12, Fig. G.26, Fig. G.27(A), Fig. G.27(B), Fig. G.29, Fig. G.30, Fig. G.31, Fig. G.32, Fig. G.33, Fig. G.34 and Fig. G.35.'

12. (*Page* 195, *Fig.* G.3) — Add the following note at the end:

'd) First sketch is permitted for Class 3 vessels only.'

13. [*Page* 197, *Fig.* G.6, *note* (b)] — Substitute the following notes for the existing note:

'b) Permitted for Class 3 vessels only.

c) Special attention should be paid to the examination of the plate edges before and after welding.'

14. [*Page* 197, *Fig.* G.7, *note* (b)] — Substitute the following for the existing note:

'b) Permitted for Class 2 and Class 3 vessels only.'

15. [*Page* 197, *Fig.* G.8, *note* (b)] — Substitute the following notes for the existing note:

'b) Its use when thermal gradient may cause overstress in welds to be avoided. Permitted for Class 2 and Class 3 vessels only. The weld sizes are minimum.

c) The pad is not to be taken into account in calculating the reinforcement required.'

Sl No.

16. (*Page* 198, *Fig*. G.12)

i) Delete the words '(Recommended for light duty vessels)'.

ii) Substitute the following for the existing note:

'a) Permitted for Class 3 vessels only.

b) The pad is not to be taken into account in calculating the reinforcement required.'

17. (*Page* 206, *Fig*. G.34) — Incorporate a fillet weld at the edge of lower plate.

18. [*Page* 207, *Fig*. G.36 (under consideration)] — Delete the figure.

19. [*Page* 209, *Fig*. G.40(B)] — Add the following note at the end and renumber the existing note as note (a):

'b) Permitted for Class 3 vessels only.'

20. (*Page* 209, *Fig*. G 41) — Add the following note at the end:

'c) Permitted for Class 3 vessels only.'

21. (*Page* 216, *Fig*. G.67)

i) Substitute the following for the existing note (b):

'b) Minimum distance between tubes=2·5 t'

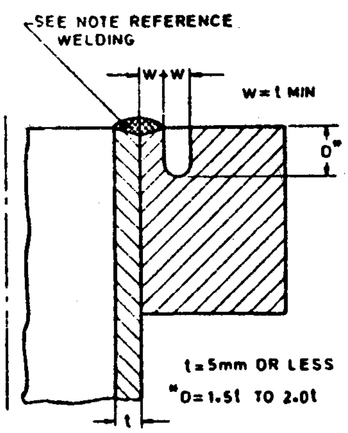
ii) Add the following new note (f):

'f) A satisfactory weld procedure should be established to ensure that the throats at all sections (minimum leakage path) shall not be less than the minimum required.'

22. (*Page* 217, *Fig*. G.70) — Add the following new note (c):

'c) A satisfactory weld procedure should be established to ensure that the throats at all sections (minimum leakage path) shall not be less than the minimum required.'

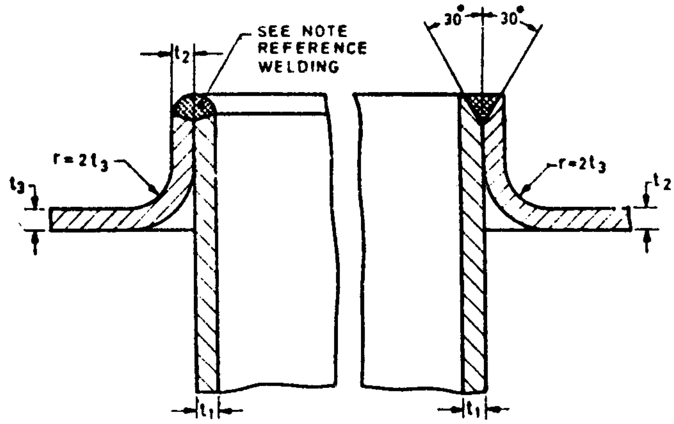
23. (*Page* 218, *Fig*. G.71) — Add the following figure (D).



(D)

Sl No.

24. (*Page* 218, *Fig*. G.72) — Substitute the following for the existing figure and the notes thereunder:



(A) (B)

a) t_1 is the thickness of the tube. It shall not be less than 2·5 mm.

b) t_3 is the original plate thickness.

c) t_2 is the plate thickness after bunging. t_2 should not be less than t_1.

d) It is uncommon for this detail to be used if the thickness of the tube or tube sheet exceeds 4 mm.

e) *Reference Welding*

The detail shown in Fig. G.70 is suitable for welding by processes other than the metal arc process. A filler rod should be used if the tube wall thickness exceeds 1·5 mm when oxy-acetylene gas welding is employed and 2·9 mm when other suitable arc welding processes are used, such as atomic hydrogen or inert gas arc welding

FIG. G.72 TUBE TO TUBE PLATE CONNECTIONS

25. (*Pages* 219 *and* 220, *Fig*. G.74, G.75, G.76, G.77, G.80, G.81, G.82) — Add the following additional note under all these figures:

'NOTE — If plate material is used for tube sheets, special attention should be given to examination of lamellar defects before and after welding.'

26. [*Page* 220, *Fig*. G.78, G.79, G.83(A), G.83(B)] — Add the following additional note for all these figures:

'NOTE — Hubs for butt welding to adjacent shell, head or other pressure parts shall not be machined from rolled plate and the component having the hub shall be forged to provide in the hub the full minimum tensile strength and elongation specified for the material in a direction parallel to the axis of the vessel. Proof of this shall be furnished by a tensile test specimen taken in this direction as close to the hub as possible.'

AMENDMENT NO. 4 MARCH 1982
TO
IS : 2825-1969 CODE FOR UNFIRED PRESSURE VESSELS

Alterations

Sl No.

1. [*Sl No.* 26 *of Amendment No.* 2 *to* IS : 2825-1969 *dated October* 1978, *new clause* **6.3.2**(a), *4th line*] — Substitute ' hole ' *for* ' whole '.

2. (*Sl No.* 24 *of Amendment No.* 3 *to* IS : 2825-1969 *dated July* 1979, *new Fig.* G.72) — Substitute ' t_2 ' *for* ' t_3 ' on the right hand side of the Fig. Also under 5th line of Note (e) substitute ' 2 mm ' *for* ' 2·9 mm '.

3. [*Page* 6, *clause* **1.2.5.2**(f)] — Add the following new clause after this clause:

   'g) Causes such as acceleration, deceleration, etc, in the case of vessels intended for transportation.'

4. (*Page* 5, *clause* **1.1.1**) — Substitute the following for the existing clause:

   '**1.1.1** This code covers minimum construction requirements for the design, fabrication, inspection, testing and certification of fusion-welded unfired pressure vessels including those intended for transportation in ferrous as well as in non-ferrous metals. '

5. [*Page* 39, *clause* **3.12.1**(c)] — Add the following new clause after this clause:

   d) A typical design of jacketed portion is covered under Appendix P.

6. (*New Appendix P*) — Add the following new Appendix P at the end of the code:

'APPENDIX P
[*Clause* 3.12.1(d)]

DESIGN OF JACKETED PORTION OF VESSEL

P-1. SCOPE

P-1.1 The rules in this appendix cover minimum requirements for the design and construction of the jacketed portion of the vessel. The jacketed portion of the vessel under analysis is defined as the inner and outer walls, the closure devices and other parts within the jacket which are subject to pressure stresses.

P-1.2 For the purpose of this part jackets are assumed to be integral pressure chambers, attached to vessels for one or more purpose such as:

a) to heat the vessel and its contents,
b) to cool the vessel and its contents, and
c) to provide a sealed insulation chamber for the vessel.

P-1.3 This appendix does not cover rules to cover all details of design and construction. These rules are, therefore, established to cover most common type of jackets but are not intended to limit configurations to those illustrated or otherwise described therein.

P-1.4 All other parts of this code shall apply unless otherwise stated in this appendix.

P-1.5 Typical jacketed connections are given in Fig. G.45 to G.66 of Appendix G.

P-2. TYPE OF JACKETS AND NOTATION

P-2.0 Jacketing of process vessels is usually accomplished by use of one of the following main available types:

a) Conventional jackets (*see* Fig. P.1 and P.2);
b) Half pipe coil jackets or limpet coil jackets (*see* Fig. P.3, P.4 and P.7);
c) Dimple jackets (*see* Fig. P.6); and
d) Heater channels type jackets (*see* Fig. P.5).

P-2.1 Conventional Jacket (*see* Fig. P.1 and Fig. P.2)

a) The normal configuration of conventional jacket is as shown in Fig. P.1, Type A. This assures the most efficient heat transfer to the maximum surface area of the vessel.
b) An often used variation of this configuration is made (*see* Fig. P.1, Type B) by dividing the straight side into two or more separate jackets.

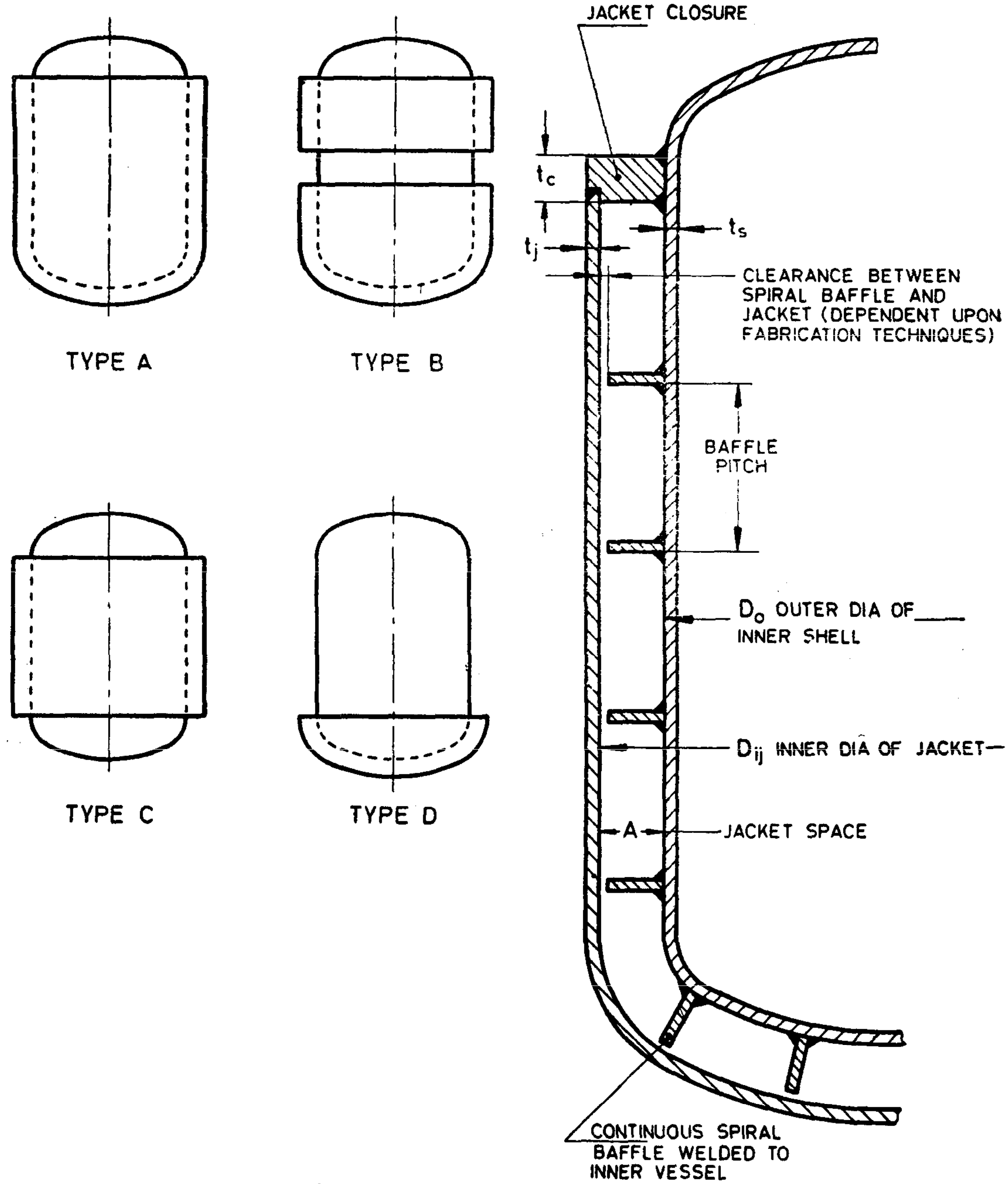


Fig. P.1 Conventional Jacket in Cross Section

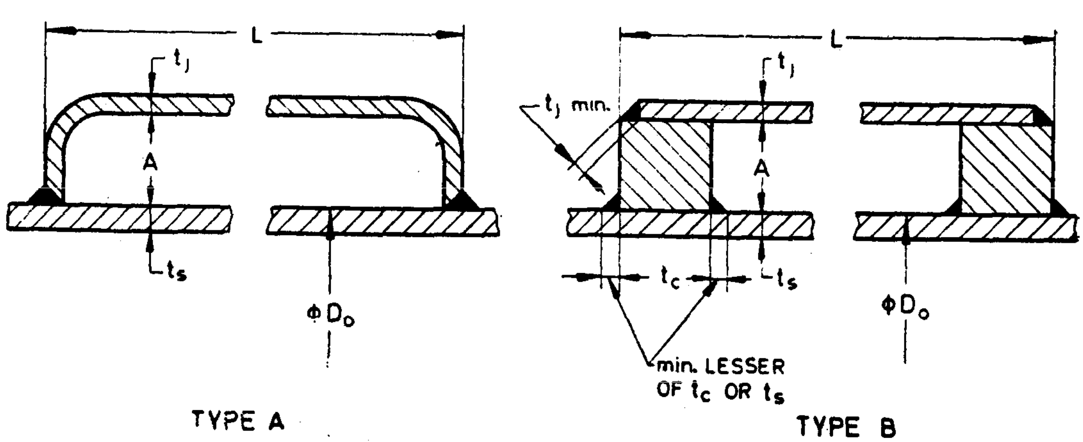


Fig. P.2 Conventional Jacket

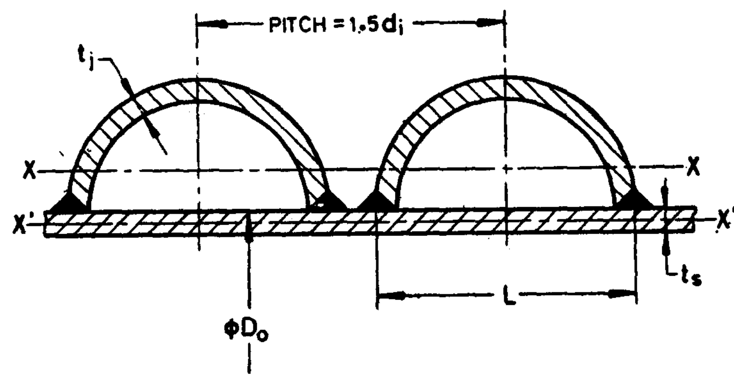


FIG. P.3 HALF PIPE COIL JACKET

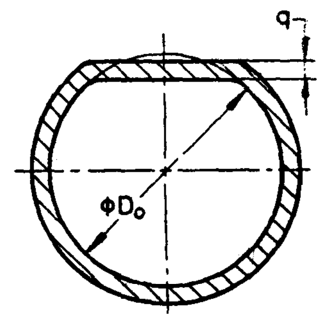


FIG. P.4 FLATNESS SECTION

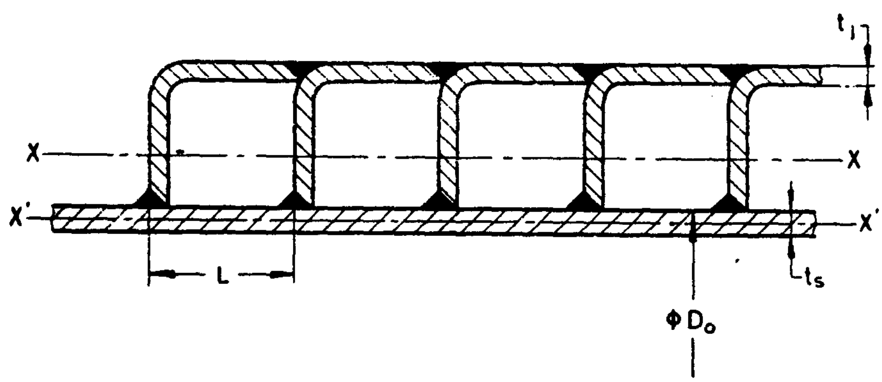


FIG. P.5 HEATER CHANNEL TYPE JACKET

c) If desired the vessel can be jacketed on the straight side on varying from complete to partial vertical coverage (*see* Fig. P.1, Type C); and

d) A jacket can also be fabricated to cover the bottom head only (*see* Fig. P.1, Type D).

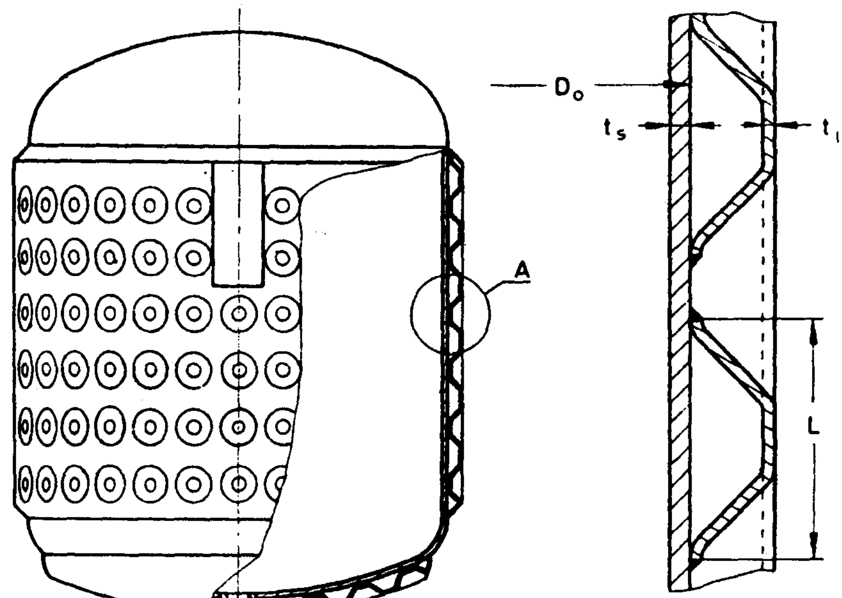
P-2.2 Half Pipe Coil Jackets or Pimpet Coil Jackets (*see* Fig. P.3 and Fig. P.7) — The half pipe coil jacket is especially recommended for high temperature services. Because there are no limitations to the number and location of inlet and outlet connections, the half pipe coil jacket can be divided into multiple zones (*see* Fig. P.7) for maximum flexibility and efficiency. The half pipe coil design usually allows reduction in thickness of inner wall of the vessel.

P-2.3 Dimple Jacket (*see* Fig. P.6) — The design of dimple jacket permits construction from light gauge metals without sacrificing the strength required to withstand specified pressures. Manifold should be designed to avoid stress concentration due to discontinuity stresses and flexible hoses should be used to eliminate all external forces on the jacket connections and their manifolds.

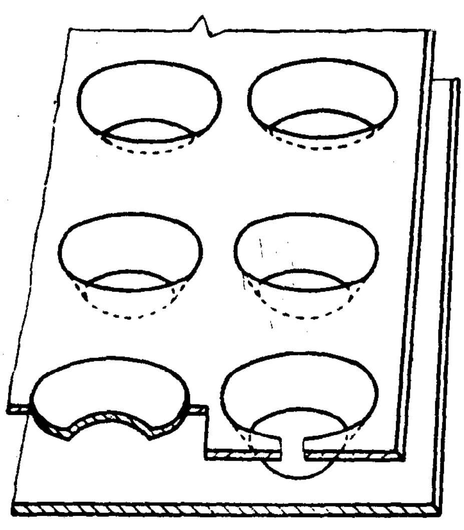
P-2.4 Notation

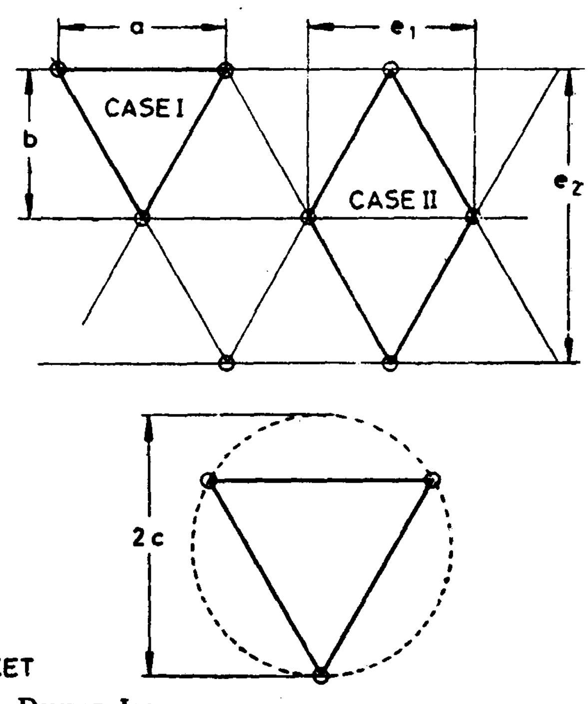
Symbol	*Unit*	*Description*
A	mm	Jacket space.
D_i	mm	Inner diameter of shell.
D_o	mm	Outer diameter of shell.
D_{ij}	mm	Inner diameter of the jacket.
d_i	mm	Inner diameter of half pipe coil.
E	kgf/mm²	Modulus of elasticity of material at operating temperature.
f	kgf/mm²	Maximum allowable stress value.
J	—	Weld joint fact
L	mm	Design length jacket section.
l/m	—	Poisson's ratio.
p	kgf/cm²	Maximum operating pressure in jacket.
P	kgf/cm²	Maximum operating pressure in shell.
t_o	mm	Thickness of closure member.

Symbol	*Unit*	*Description*
t_j	mm	Thickness of outer jacket wall.
t_s	mm	Thickness of inner vessel wall.
t_{rc}	mm	Required minimum thickness excluding corrosion allowance of the closure member.
t_{rj}	mm	Required minimum thickness of outer jacket wall exclusive of corrosion allowance and manufacturing tolerances.
t_{rs}	mm	Required minimum thickness of inner shell wall exclusive of corrosion allowance and manufacturing tolerances.



ENLARGED DETAIL AT A





VIEW OF VESSEL WITH DIMPLE JACKET

Fig. P.6 Dimple Jacket

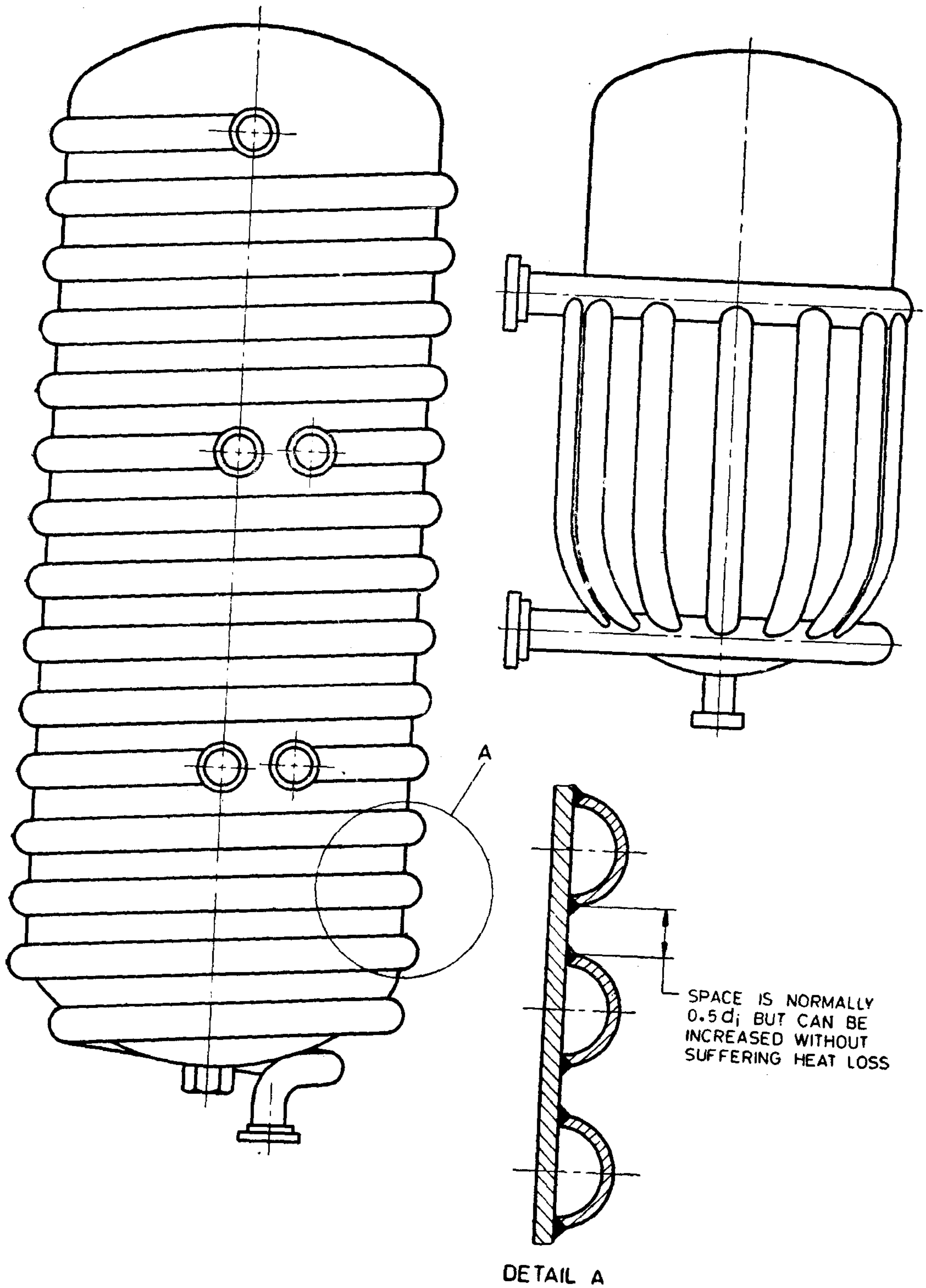


FIG. P.7 HALF PIPE COIL JACKET

P-3. DESIGN CRITERIA

P-3.1 Conventional Jacket

P-3.1.0 Design shall comply with the applicable requirements of the code except where otherwise provided for in the appendix.

P-3.1.1 Shell and head thickness shall be determined by the appropriate formulae given in Section 3 of this Code. In consideration of loadings particular attention to the effects of local internal and external loads and expansion differentials at the design temperature shall be given. Where vessel supports are attached to the jacket, consideration shall be given to the transfer of supported load of the inner vessel and contents.

P-3.1.2 The use of impingement plates or baffles at the jacket inlet connection to reduce erosion of inner wall shall be considered for media where vapours are condensed, that is, steam.

P-3.1.3 The width of jacket space shall not exceed the value given below:

$$A = \frac{400 \times f \times J \times t_s^2}{p \times D_{1j}} - 0{\cdot}5\,(t_s + t_j) \qquad \text{...... (P.1)}$$

P-3.1.4 *Design for Jacket Closures*

P-3.1.4.1 Closures of Type B of Fig. P.2 (Fig. G-55 modified) shall be used only for Type C of Fig. P.1 jacketed vessels and with further limitation that t_{rj} does not exceed 15 mm. The required minimum thickness for the closure bar shall be greater of the following:

$$t_{rc} = 2\,(t_{rj}) \qquad \text{...... (P.2)}$$

$$t_{rc} = 0{\cdot}086\,6 \times A \times \sqrt{\frac{p}{f}} \qquad \text{...... (P.3)}$$

P-3.1.4.2 Closure bar and closure bar to inner vessel welds of the type shown in Fig. G.49, G.50, G.51 may be used in any of the types of the jacketed vessels shown in Fig. P.1. The required minimum closure bar thickness shall be determined as below:

$$t_{rc} = 0{\cdot}122\,47\sqrt{\frac{pD_0A}{f}} \qquad \text{...... (P.4)}$$

P-3.1.5 Minimum weld size requirements are as detailed in Fig. G.45 to G.59.

P-3.2 Half Pipe Coil Jackets

P-3.2.1 The foregoing analysis is based on the following assumptions which may be suitably modified in case of any variations.

a) shell and half coil are made of the same metal,

b) the half coil is semicircular,

c) both shell and coil cylinders are considered as thin in relation to their diameters,

d) the coils shall be pitched not less than $1\frac{1}{2}$ times d_1, centres apart, and

NOTE — Very close spacing of coils is not recommended as it leads to bad weld joint, yields very little heat transfer benefit as the space in between the coils has an effect like fin on a finned tube.

e) half coil takes no load in comparison with the shell.

P-3.2.2 *Design of Half Coil*

P-3.2.2.1 A half coil is a part of torous for which stresses have been analyzed by 'Timoshenko'. It can be shown that maximum hoop stress in the coil will occur at the junction with the shell and is

$$f_{c1} = \frac{p\,d_1}{200 \times t_{rj} \times J} \qquad \text{...... (P.5)}$$

and longitudinal stress is

$$f_{c2} = \frac{p\,d_1}{400\,t_{rj} \times J + 250\,t_{rs} \times J} \qquad \text{.. (P.6)}$$

The half coil is, therefore, usually designed on a simple hoop stress basis.

P-3.2.3 *Design of Shell*

P-3.2.3.1 *Total hoop stress* — The total hoop stress in the shell, f_{st} is, sum of the hoop stress f_{s1} due to vessel pressure, and longitudinal stress f_{c2} in the coil caused by coil pressure.

$$f_{st} = \frac{P\,D_1}{200\,t_{rs} \times J} + \frac{p\,d_1}{400\,t_{rj} \times J + 250\,t_{rs} \times J} \qquad \text{...... (P.7)}$$

P-3.2.3.2 *Total longitudinal stress*

a) The total longitudinal stress in the wall is made of three factors:

1) the longitudinal stress f_{s2} due to vessel pressure,

2) the longitudinal stress f_{s3} due to coil pressure,

3) the bending stress f_{s4} caused by distortion of the shell at the junction with the coil.

$$f_{s2} = \frac{P\,D_1}{400 \times t_{rs} \times J} \qquad \text{...... (P.8)}$$

$$f_{s3} = \frac{p\,d_1}{200 \times t_{rs} \times J} \qquad \text{...... (P.9)}$$

b) The local bending stress in the shell due to the pressure in the coil should be assessed for the case when the internal pressure for the vessel is at its minimum, that is, atmospheric or vacuum. A simplified approximation based on 'Continuous Beam Theory' predicts a maximum bending moment, M_{max} in shell of:

$$M_{max} = \Delta P\,d_0^2/900 \qquad \text{...... (P.10)}$$

Also

$$f_{s4} = \frac{2\,\Delta P\,d_0^2}{300\,t_{rs}^2} \qquad \text{...... (P.11)}$$

(Negative value of $\triangle P = (p - P)$ need not be considered as this refers to high internal pressure. Bending moment due to internal pressure is insignificant compared with direct membrane forces which must have already been allowed for the hoop stress calculations.

$$f_{sL} = f_{s2} + f_{s3} + f_{s4} \quad \text{...... (P.12)}$$

c) For critical analysis 'Cylindrical Shell Theory' concept may be followed.

P-3.2.4 *Maximum Equivalent Stress at Coil to Shell Junction*

The metal at the junction of coil to shell is subject to all individual stresses present in shell and coil and maximum equivalent stress occurs at shell to coil junction. This can be analyzed by 'Shear Strain Energy Theory' which adds the principle stresses acting mutually at right angles to give the equivalent stresses.

$$f_e^2 = f_{sl}^2 + f_{st}^2 + f_{cl} - (f_{sl} \times f_{st} + f_{sl} \times f_{cl} + f_{st} \times f_{cl}) \quad \text{... (P. 13)}$$

It is prudent to check that this is within the allowable value.

P-3.2.5 As a steam coil may be subjected to vacuum (if steam is turned off) there are any possible ~~combinations of pressure~~ to vacuum in coil with pressure to vacuum in the shell and this gives 4 distinct limiting cases in the region of the coil. There are further 2 cases in the region where there is no coil corresponding to vacuum or pressure in the vessel with atmospheric pressure outside. By analyzing the stresses in details as indicated above, it is quite advisable to analyze the six conditions to determine the worst one.

P-3.2.6 *Vessel Bottoms* — It is extremely difficult to cut a half coil to suit a hemispherical or conical vessel bottom. Preferable methods in this regard should be decided between the manufacturer and designer. The recommended practice is to arrange pattern of coils radially like hub spokes and rim of a wheel.

P-3.2.7 One difficulty leading to failure of the bottom end of the half coil has been traced to be 'Steam Hammer' when steam is used intermittently in a batch process. The steam entering a cold vessel causes condensate to accelerate round the coils and hammer the exit branch and coil ends. For this reason the coil length should be limited to not more than three turns in series (*see* Fig. P.9). The exit nozzle should be swept rather than right angular and care taken in design of steam trap manifold.

P-3.3 Dimple Jackets

P-3.3.1 *Dimple Plate Thickness*

P 3.3.1.1 *Case I (see Fig. P. 8)* — Considering fixed plate with uniformly distributed load over the entire surface:

$$\text{Maximum stress at edge, } f_{ed} = \frac{3 \times W}{4\pi \times t_{rj}^2} \quad \text{...... (P.14)}$$

Maximum deflection at the centre

$$y = (-)\frac{3 \times W(m^2 - 1) \times C^2}{16 \times \pi \times E \times m^2 \times t_{rj}^3} \quad \text{...... (P.15)}$$

P-3.3.1.2 *Case 2* — Dimples can be assumed to act as 'stays' in flat heads and plate thickness is checked as below, both for:

a) uniform spacing of staying, and

b) non-uniform spacing of the staying

P-3.3.1.3 *Case 2 (a)—Uniform spacing of stays (see* Fig. P.7)

$$t_{rj\,min} = C \times \sqrt{\frac{p\,(a^2 + b^2)}{100 \times f}} \quad \text{...... (P.16)}$$

P-3.3.1.4 *Case 2 (b) — Non-uniform spacing of stays (see* Fig. P. 7)

$$t_{rj\,min} = C \times \frac{c_1 + c_2}{2}\sqrt{\frac{p}{100\,f}} \quad \text{...... (P. 17)}$$

where $C = 0.40$ for welded stays.

The adopted thickness (t_j) shall include corrosion and manufacturing allowances, etc.

P-3.3.2 *Dimple Connecting Welds* — The weld attachment is made by fillet welds around holes, or if the thickness of the plate having hole is 5 mm or less and hole is 25 mm or less in diameter, the holes may be completely filled with weld metal. The allowable load on weld shall equal the product of the thickness of plate having the hole, the circumference or perimeter of hole, the allowable stress value in tension of the material being welded and joint efficiency of 55%. The connecting welds shall be checked for shear and tear failures.

P-4. CONSIDERATIONS OF STIFFENING EFFECT OF JACKET ELEMENTS (*see* Fig. P.2 to P.6)

P-4.1 Calculations for Elastic Buckling

Maximum working pressure, $P =$

$$\frac{E}{3}\left[\frac{200\dfrac{l}{n^2}\times\dfrac{t_{rs}}{D_0}}{\left[1+\left(\dfrac{2nL}{\pi D_0}\right)^2\right]^2}+\frac{200n^2}{3}\left[1+\left(\frac{\pi D_0}{2nL}\right)^2\right]^2 \times \frac{m^2}{m^2-1}\times\frac{t_{rs}^3}{D_0^3}\right]\times\left[\frac{1}{1+\frac{1}{2}\left(\dfrac{\pi D_0}{2nL}\right)^2}\right] \quad \text{...... (P.18)}$$

and 'n' should be chosen as a whole number $\left[n \geqslant 2 \geqslant \frac{\pi D_o}{2L}\right]$ in such a way that p is at its lowest value. 'n' is then the number of dents which may appear on the surface in the event of failure.

P-4.2 Calculation for Plastic Deformation

P-4.2.1 *Case 1* — When $\frac{D_o}{L} \leqslant 5$, the maximum permissible working pressure is given by:

$$P = 200 \times f \times \frac{t_{rs}}{D_o} \times \frac{1}{1 + \dfrac{1.5\,U\left(1 - \dfrac{0.2\,D_o}{L}\right)}{100\,t_{rs}/D_o}} \quad \ldots \text{(P.19)}$$

where U = out of roundness factor.

a) For ovality $U = 2 \times \frac{D_i\,max - D_i\,min}{D_i\,max + D_i\,min} \times 100$

b) For flatness $U = \frac{4}{D_o} \times q \times 100$ (*see* Fig. P.4).

P-4.2.2 *Case* 2 — When $\frac{D_o}{L} > 5$

$$P = \text{Greater of } \frac{200 \times f \times t_{rs}}{D_o} \text{ or } \frac{300 f \times t_{rs}^{2*}}{L^2} \quad \ldots\ldots \text{(P.20)}$$

P-4.2.3 In vacuum vessels the stiffening effect of the jacket elements (half pipe coils, heater channels, etc) may be taken into consideration in calculating the whole shell. For elastic buckling analysis the permissible pressure will then be greater, in proportion to the moment of inertia (taken about the axis through the appropriate centre of gravity X-X, or X′-X′) and for plastic deformation analysis the permissible pressure will be greater in proportion to the cross-sectional areas with and without the jacketing elements.

*This formula is particularly applicable when distance between stiffeners is small.

P-5. FABRICATION

P-5.1 Fabrication of vessels shall be in accordance with applicable parts of the code.

P-5.2 This part covers fabrication of jacketed vessels by welding. Other methods of fabrication are permitted provided the requirements of applicable parts of this section are met.

P-5.3 Where only the inner vessel is subject to lethal service the requirements regarding radiography, post weld heat treatment shall apply only to the welds in the inner vessel and those welds attaching the jacket to the inner vessel need not be radiographed and may be fillet-welded. Post weld heat treatment shall be as required in **6.12** of the code.

P-5.4 Proper testing for pinholes in the welds is mandatory.

P-5.5 Any radial welds in closure members shall be butt-welded joints penetrating through the full thickness of the member and shall be ground flush where attachment welds are to be made.

P-6. APPLICATIONS

P-6.1 Conventional jackets are used where the internal pressure of the vessel is more than twice the jacket pressure, the jacket pressure being limited to 7 kgf/cm².

P-6.2 Dimple jackets and half-pipe coil jackets are used for vessels beyond 2m³ capacity and where the jacket pressure is the controlling factor (that is, the vessel internal pressure is less than 1·67 times the jacket pressure) in determining the vessel wall thickness. These are used for high pressure (that is, dimple jackets up to 21 kgf/cm² and half pipe coil jackets up to 52·5 kgf/cm²) and high temperature applications.

NOTE — For high temperature applications thermal expansion differentials should be considered between the metals used in the vessel and the jacket, and difference in thicknesses between the vessel and the jacket walls, and for temperatures beyond 300°C the jacket be fabricated from a metal having the same coefficient of expansion as that used for the inner vessel.

Printed at Kay Kay Printers, Delhi

AMENDMENT NO. 5 OCTOBER 1988
TO
IS : 2825 - 1969 CODE FOR UNFIRED PRESSURE VESSELS

(*Page* 9, *clause* **1.3.1.3**, *line* 4) — Add the words 'or gas' after the word 'vapour'.

(*Page* 9, *clause* **1.3.1.3**)

a) *Line* 4 — Add the words 'or gas' after the word 'vapour'.

b) *Line* 5 — Delete the word 'design'.

NOTE — Hydrostatic pressure means pressure due to liquid head only.

[*Page* 14, *Tables* 3.1, 3.2, 3.3 *and* 3.4 (see also *Amendment No.* 2, *Sl No.* 11)] — Retain the tables with all the existing matter.

[*Page* 21, *clauses* **3.4.6.1**(a) *and* **3.4.6.2**(a), *line* 4 (see also *Amendment No.* 2, *Sl No.* 12 *and* 13)] — Substitute '**3.3.3.1**' *for* '**3.3.3.3**'.

[*Page* 35, *clause* **3.8.7.1**(b), *line* 2] — Substitute 'P2 (50 mm nominal bore)' *for* 'P 1½ size'.

(*Page* 36, *clause* **3.9.4**, *last line*) — Substitute 'P2 (50 mm nominal bore)' *for* 'size P 1½'.

(*Page* 65, *clause* **6.2.5**, *first para*) — Substitute the following for the existing para:

'Any person who wishes to qualify for welder's performance test under this code, shall not be below the age of 18 years and shall have adequate experience or training.'

(*Page* 71, *clause* **6.4.10**, *last sentence*) — Substitute the following for the existing sentence:

'If the forming or bending operation takes place in hot condition, no subsequent heat treatment is required, provided during the last operation, it is uniformly heated to a temperature within the normalizing range.'

[*Page* 71, *clause* **6.4.11**, *first sentence* (see also *Amendment No.* 3, *Sl No.* 6)] — Substitute the following for the existing sentence:

'**6.4.11** *Plates Welded Prior to Forming* — Seams in plates may be welded prior to forming provided they are examined radiographically throughout the entire length after forming. In the case of class 1 and 2 vessels, the seams shall also be inspected by magnetic crack detection or dye-penetrants.'

(*Page* 71, *clause* **6.5.1**, *last sentence*) — Substitute the following matter for the existing sentence:

'Tack welds shall either be removed completely when they have served their purpose or their stopping and starting ends shall be properly prepared by grinding or other suitable means so that they may be satisfactorily incorporated into the final weld. Tack welds shall be made by qualified procedures and welders, and shall be examined visually for defects and, if found to be defective, shall be removed.'

[*Page* 75, *clause* **6.12.2**(a)] — Substitute the following for the existing matter:

'a) intended for containing lethal* material;'

[*Page* 75, *clause* **6.12.2**(g)] — Add the following new items after **6.12.2**(g).

'h) intended for transport of flammable or toxic material; and

j) when required by the statutory authority.'

(*Page* 76, *Table* 6.3):

a) *Material Group* 2a — Substitute 'Sum of alloying elements, that is, Cr, Mo and V 0·80 *Max*' *for* 'Residual or other elements 0·80 *Max*'.

b) Renumber material group '2a' as '2'.

c) Renumber material group '2b' as '3'.

d) Delete the present material group '3'.

[*Page* 77, *clause* **6.12.3.1**(b), *line* 6] — Substitute '$2{\cdot}5\sqrt{rt}$' *for* '$5\sqrt{rt}$'.

(*Page* 96, *clause* **8.4.2.2**, *para* 3, *first sentence*) — Substitute the following for the existing sentence:

'The vessel shall be maintained at the specified test pressure for a sufficient length of time to stabilize the pressure but in no case less than 10 minutes. A thorough examination of the vessels shall be carried out after lowering the pressure to 80 percent of the test pressure.'

(*Page* 96, *clause* **8.4.2.2**, *para* 3, *second and third sentences*) — Delete.

(*Page* 96, *clause* **8.5.1**)—Substitute the following for the existing clause:

'**8.5.1** Two production test plates representing approximately 15 metres of weld or five shell courses, whichever is higher, shall be provided with longitudinal seams for every weld procedure applicable to the vessels or series of vessels made to the same drawing/specification. Vessels having more than 5 shell courses shall be provided with an additional production test plate representing the next 15 metres of welding or part thereof. No test plate need be provided for circumferential seams except in cases where a vessel has circumferential seams only or the welding process, procedure or technique is substantially different, in which case two test plates are to be provided.

8.5.1(a) For low temperature vessels, in addition to the test coupon plates mentioned in **8.5.1**, each other shell course shall also be provided with a coupon plate sufficiently long for testing two sets of impact test (one for weld metal and one for heat affected zone). One set of tests shall be conducted to cover 5 seams.

See* **1.3.1.1(a) regarding clarification of the word 'lethal'.

8.5.1(b) For vessels other than covered under **8.5.1** (a), any one test plate shall be selected by the inspector for all tests described in figures under **8.5.1.2** of the code except for all weld metal tensile test.'

[*Page* 99, *Fig.* 8.5(A)] — Delete.

[*Page* 99, *Fig.* 8.5(B)] — Delete the letter '(B)' from the title of bottom figure and substitute 'Fig. 8.5' *for* 'Fig. 8.5(B)' wherever occurs in this code.

(*Page* 102, *clause* **8.6.2**) — Substitute the following for the existing clause:

'**8.6.2** The minimum average impact strength value for the impact test piece shown in Fig. 8.5 for V-notch specimen shall be 2·8 kgf.m (3·5 kgf m/cm^2). The minimum impact strength value for any test piece shall be 2·1 kgf.m (2 6 kgfm/cm^2).

NOTE — The value is equivalent to 2·8 kgf.m for a 10 × 10 mm test piece.'

(*Page* 103, *clause* **8.6.8**, *line* 4) — Substitute 'retests' *for* 'new tests'.

(*Page* 104, *clause* **8.7.2.1**)—Add the following at the end of the clause:

'[*see also* **8.7.10.3**(b)]'

(*Page* 104, *clause* **8.7.3.3**) — Substitute the following for the existing clause:

'**8.7.3.3** Radiographic examination may be conducted before the final heat treatment. However for chromium molybdenum steels having the chromium content equal to or more than 1·5 percent radiography is recommended after heat treatment.'

(*Page* 115, *Table* A.1)— Delete the reference to IS : 1570-1961 wherever mentioned.

(*Page* 195, *Fig.* G.1) — Substitute 'Nominal pipe size 50 mm *Max*' *for* 'BORE *MAX* 100 mm NOMINAL'.

[*Page* 195, *Fig.* G.1, *foot-note* (b)] — Substitute 'P2 (50 mm nominal bore)' *for* 'size 1½'.

[*Page* 195, *Fig.* G.2, *foot-note* (b)] — Substitute 'P2 (50 mm nominal bore)' *for* ' size 1½'.

[*Page* 195, *Fig.* G.3, *foot-note* (c)] — Substitute 'P2 (50 mm nominal bore)' *for* 'size 1½'.

(*Page* 196, *Fig.* G.4, *foot-note* (d)] — Substitute 'P2 (50 mm nominal bore)' *for* 'size 1½'.

[*Amendment No.* 4, *page* 1, *clause* **P-2.0**(c)] — Substitute the following for the existing item:

'c) Dimple jackets (*see* Fig. P.6); and'

[*Amendment No.* 4, *page* 3, *clause* **P-2.1** (c), *line* 2] — Substitute 'only' *for* 'on'.

(*Amendment No.* 4, *page* 3, *clause* **P-2.2**, *Heading*) — Substitute the following for the existing heading:

'P-2.2 Half Pipe Coil Jackets or Limpet Coil Jackets (*see* Fig. P.3, P.4 and P.7)'

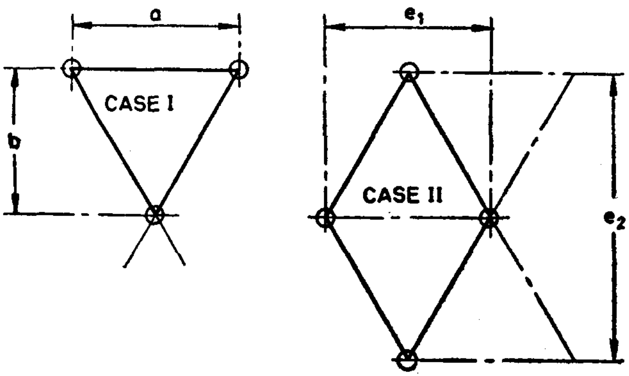
(*Amendment No.* 4, *page* 3, *clause* **P-2.2**)—Add the following new clause after **P-2.2**:

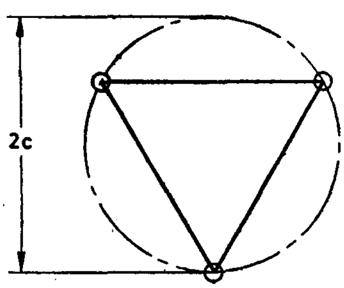
'**P-2.2.1** *Notation*

Symbol	*Unit*	*Description*
f_{c1}	kgf/mm^2	Hoop stress in the coil due to coil pressure
f_{c2}	kgf/mm^2	Longitudinal stress in the coil due to coil pressure
f_{st}	kgf/mm^2	Total hoop stress in the shell
f_{s1}	kgf/mm^2	Hoop stress in the shell due to coil pressure
f_{s2}	kgf/mm^2	Longitudinal stress in the shell due to vessel pressure
f_{s3}	kgf/mm^2	Longitudinal stress in the shell due to coil pressure
f_{s4}	kgf/mm^2	Longitudinal stress in the shell due to bending
a b	— —	Spacing of dimples as per Case 1 (Uniform spacing of dimples) (Fig. P.6)
c	mm	Radius of loaded area considered (Fig. P.6)
e_1 e_2	— —	Spacing of dimples as per Case 2 (Non-uniform spacing of dimples) (Fig. P.6)
W	kgf	Total load uniformly distributed over area of radius 'c' (Fig. P.6)]
m	—	Inverse of Poission's ratio
C	—	Constant concerning the load conditions
f_{SL}	kgf/mm^2	Total longitudinal stress in the shell (in case of half pipe coil type of jackets) (*see* Equation P.12).
f_e	kgf/mm^2	Maximum equivalent stress at the half pipe coil to shell junction (*see* Equation P.13)
f_{ed}	kgf/mm^2	Maximum stress in the dimple jacket wall'

(*Amendment No.* 4, *page* 3, *clause* **P-2.4**) — Substitute '$1/m$' *for* 'l/m'.

(*Amendment No.* 4, *page* 4, *Fig.* P.6) — Delete the two existing figures given on the right hand bottom on this page and add the following new figures.





(*Amendment No.* 4, *page* 7, *clause* **P-3.2.4**, *equation* P.13) — Substitute the following for the existing equation:

$$f_e^2 = f_{s1}^2 + f_{st}^2 + f_{o1}^2 - f_{s1} \times f_{st} + f_{s1} \times f_{o1} + f_{st} \times f_{o1} \qquad \text{... (P.13)}$$

(*Amendment No.* 4, *page* 7, *clause* **P-3.3**) — Substitute the following for the existing clause:

'P-3.3 Dimple Jackets

P-3.3.1 *Dimple Plate Thickness* — Dimples can be assumed to act as 'stays' in flat heads and plate thickness is checked below, both for:

a) Case 1—Uniform spacing of stays; and

b) Case 2—Non-uniform spacing of stays.

P-3.3.1.1 *Case* 1—Uniform spacing of stays (*see* Fig. P.6).

$$t_{rj}\,Min = C \times \sqrt{\frac{p\,(a^2 + b^2)}{100 \times f}} \qquad \text{... (P.14)}$$

P-3.3.1.2 *Case* 2—Non-uniform spacing of stays (*see* Fig. P.6)

$$t_{rj}\,Min = C \times \frac{e_1 + e_2}{2} \sqrt{\frac{p}{100 \times f}} \qquad \text{... (P.15)}$$

where $C = 0{\cdot}40$ for welded stays.

P-3.3.2 *Checking for Stress and Deflection* (see *Fig.* P.6) — Considering fixed plate with uniformly distributed load over the entire surface.

P-3.3.2.1 Maximum stress at the edge,

$$f_{ea} = \frac{3W}{4 \times t_{rj}^2} \qquad \text{... (P.16)}$$

P-3.3.2.2 Maximum deflection at the centre

$$y = (-)\,\frac{3 \times W\,(m^2 - 1) \times c^2}{16\pi \times E \times m^2 \times t_{rj}^2} \qquad \text{... (P.17)}$$

The adopted thickness (t_j) shall include corrosion and manufacturing allowances, etc.

P-3.3.3 *Dimple Connecting Welds* — The weld attachment is made by fillet welds around holes, or if the thickness of the plate having hole is 5 mm or less and hole is 25 mm or less in diameter, the holes may be completely filled with weld metal. The allowable load on weld shall equal the product of the thickness of plate having the hole, the circumference of perimeter of hole, the allowable stress value in tension of the material being welded and joint efficiency of 55 percent. The connecting welds shall be checked for shear and tear failures.'

(*Pages* 79 *to* 91, *Section* II, *Chapter* 7) — Substitute the following for the existing matter:

'7. WELDING QUALIFICATIONS

7.0 Foreword — This chapter deals with the commonly used welding processes namely manual metal arc, submerged arc, gas shielded tungsten arc, gas shielded metal arc and oxyacetylene process only. For other processes, the requirements are to be mutually agreed between the manufacturer/contractor and the authorized inspector.

7.1 Manufacturer's Responsibilities

7.1.1 Each manufacturer or contractor is responsible for the welding done by his organization. He shall establish the procedure and conduct the tests required in this section to qualify the welding procedures and the performance of welders and welding operators who apply these procedures.

7.1.2 When a manufacturer or contractor establishes proof satisfactory to the inspector that he has previously made successful procedure qualification tests in accordance with a recognized standard, such a firm shall be exempted from the necessity of requalification provided all the requirements of this section are met.

7.1.3 The parameters applicable to the welding he performs shall be listed in a document known as 'Welding Procedure Specification' (WPS) (*see* Appendix H of the code for suggested WPS format). The WPS shall be qualified by welding test coupons and testing the specimens as required in this section. The WPS shall describe all of the essential and non-essential variables of **7.3** and **7.4** for each welding process used inWPS. The WPS may be used to provide direction to the welder or welding operator and may include any other information that may be helpful in making a weldment. The welding data and test results

shall be recorded in a document known as 'Procedure Qualification Record' (PQR) (*see* Appendix H for suggested PQR format). The PQR is a record of what happened during a particular welding test and changes to PQR are not permitted unless requalified by the manufacturer or contractor.

7.1.4 Test plate is to be welded by the manufacturer or contractor and he may subcontract testing.

7.2 Test Positions

7.2.1 All test welds for welding procedure qualification shall be carried out as groove welds in any of the positions described in the following paragraphs, except that the angular deviation shall be within ± 15 degree from the specified horizontal and vertical planes and ± 5 degree from the specified inclined plane.

7.2.2 The following are the basic positions for welding (*see* Fig. 7.1).

7.2.2.1 *Flat position* — Plate in horizontal plane with the weld metal deposited from above. Pipe with its axis horizontal and rolled during welding so that the weld metal is deposited from above (*see* Fig. 7.1 A-1 and Fig. 7.1 A-2).

7.2.2.2 *Horizontal position* — Plate in vertical plane with the axis of weld horizontal:

Pipe with its axis vertical and the axis of weld in horizontal plane:

Pipe shall not be rotated during welding (*see* Fig. 7.1 B-1 and Fig. 7.1 B-2).

7.2.2.3 *Vertical position* — Plate in vertical plane with the axis of weld vertical (*see* Fig. 7.1C).

7.2.2.4 *Overhead position* — Plate in horizontal position with the weld metal deposited from underneath (*see* Fig. 7.1D).

7.2.2.5 *Multiple position horizontal* — Pipe with its axis horizontal and the welding groove in a vertical plane. Welding shall be done without rotating the pipe so that weld metal is deposited in multiple position (*see* Fig. 7.1E).

7.2.2.6 *Multiple position inclined* — Pipe with its axis inclined at 45° to horizontal. Welding shall be done without rotating the pipe (*see* Fig. 7.1F).

7.3 Essential Variables — Procedure qualification is required whenever there is a change in the welding condition which will affect the properties of the weldment, namely, change in the material group, welding process, filler metal, preheat or postweld heat treatment. Retesting is also required beyond the range qualified and for any change in position, for low temperature vessels.

7.3.1 *Base Metal* — Procedure qualification required in the following cases.

7.3.1.1 A change from a base metal listed under one metal group given in Table 6.3 of the code to the metal listed under another with the same metal group, the procedure qualified on metal with certain minimum tensile strength does not qualify for welding metal with higher specified tensile strength.

7.3.1.2 When a joint is made between two base metals that have different material groups even though qualification testing have been made for each of the two base metals welded to itself.

7.3.1.3 When the thickness of base metal is beyond the range qualified in accordance with Table 7.1 and **7.3.1.5** and **7.3.6.3**.

7.3.1.4 Any major change in weld preparation details for low temperature operation and single-sided joint.

7.3.1.5 For the short circuiting transfer made of the gas shielded arc process when the thickness exceeds 1·1 times the thickness of test coupon.

7.3.2 *Welding Process* — For each welding process a new WPS is required and each process shall be qualified. This may be qualified either separately or in combination with other processes. For multi-processes, the qualified thickness of each process shall not be additive in determining the thickness qualified.

7.3.3 *Filler Metal* — The filler metal classification to be used on the production weld should be same as the one used for procedure qualification. Any appreciable variation in the filler metal classification from the one used for the procedure will require requalification. In case of single welded joint, a change of more than one-third in the diameter of electrode for root run of manual metal arc welding requires requalification for low temperature operation.

7.3.4 *Position (Low Temperature Vessels only)* — The change of position is an essential variable for low temperature vessels only and requires requalification. However, if the position qualified is vertical up, it qualifies for other positions also. In vertical position, a change from stringer bead to weave bead calls for requalification.

7.3.5 *Preheat* — The miuimum preheat temperature shall be specified in WPS. A decrease of more than 50 degree celsius and an increase of more than 100 degree celsius for low temperature and stainless steel jobs from the minimum specified shall require requalification.

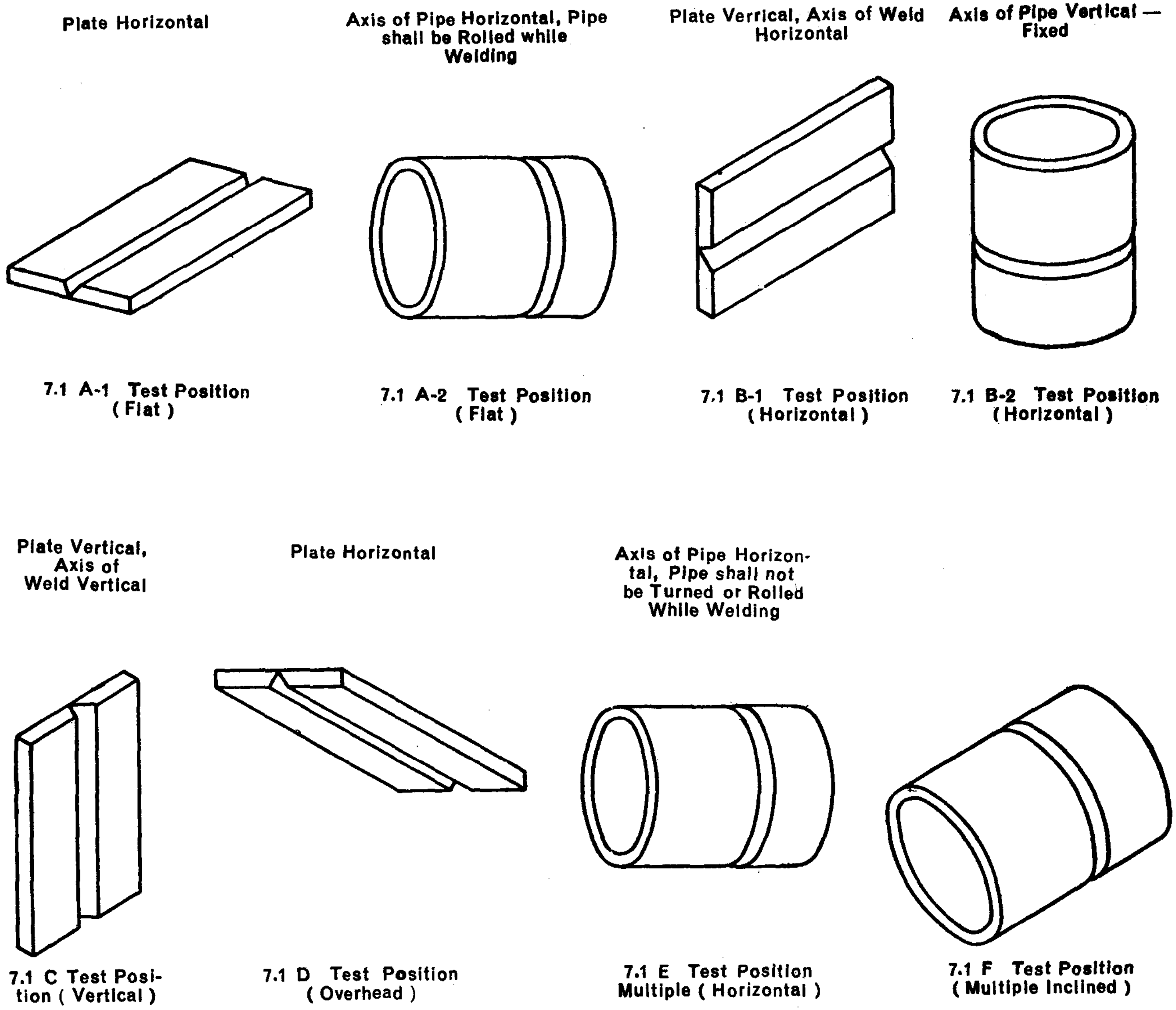


Fig. 7.1 Positions of Test Plates or Pipes for Welder Qualification and Performance of Butt Welds

TABLE 7.1 GROOVE-WELD PROCEDURE QUALIFICATION — THICKNESS LIMITS AND TEST SPECIMENS

(*Clauses* 7.3.1.3, 7.5.1, 7.6.9, 7.7.2 *and* 7.7.4)

Thickness '*T*' of Test Coupon (*see* Note 1.1) mm	Range of Thickness of Base Metal Qualified (*see* Notes 1 and 7)		Range of Thickness '*t*' of Deposited Weld Metal Qualified	Types and Number of Tests Required							
	Min (*see* Note 5) mm	*Max* mm	*Max* (*see* Notes 1 and 7) mm	Reduced Section Tension (*see* 7.5.2)	All Weld Metal Tension	Transverse Face Bend (*see* 7.5.4 and Notes 1.2 and 3)	Transverse Root Bend (*see* 7.5.4 and Notes 1.2 and 3)	Side Bend	Notched Bar Impact (*see* 7.5.1.4 and Notes 4 and 6): Weld Metal	Notched Bar Impact: Heat Affected Zone	Macro and Hardness (*see* 7.5.1.5 and 7.5.1.6 and Note 6)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Below 3	*T*	3	3	1	—	2	2	—	—	—	1
3 up to and including 10	3	2*T*	2*t*	1	—	2	2	—	3	3	1
Over 10 but less than 20	5 (*see* Note 7)	2*T*	2*t*	1	1	2	2	(*see* Note 2)	3	3	1
20 and less than 40	5	2*T*	2*t*	1	1	—	—	4	3	3	1
40 and above	5	200	200 when $t > 40$	1	1	—	—	4	3	3	1

Note 1 — When the groove is filled using a combination of welding processes and/or welding procedures with the same process (one welding process with a different combination of essential variable).

Note 1.1 — The thickness *t* of the deposited weld-metal for each welding procedure shall be determined and used in the thickness *t* of deposited weld metal column. The test coupon thickness *T* is applicable for the base metal for each welding procedure and shall be used in the range of thickness of base metal column.

Note 1.2 — The deposited weld metal of each welding process and of each welding procedure shall be included on the tension side of the bend when these test samples are used.

Note 1.3 — Each welding process and each welding procedure qualified in this combination manner may be used separately, only within the same essential variables and within the thickness limits described in this table.

Note 2 — Side-bend test may be substituted for the required face and root bend tests, when thickness *T* is over 10 mm but less than 20 mm.

Note 3 — Longitudinal face and root bend tests may be substituted for the required transverse face, root and side bend tests, when the bending properties of the two base metals or the weld metal and the base metal differ markedly (*see* **7.5.4** and **7.5.5**).

Note 4 — Out of three specimens for notched bar impact test for weld metal as well as heat.affected zone (HAZ), two specimens shall contain the face side of the joint and one specimen the root side of the joint. These form one set of specimens (*see* **7.5.6**).

Note 5 — *See* also **7.3.1.5** and **7.3.6.3** for further limitations on range of thickness of base metal qualified. For oxy-acetylene welding the test piece thickness shall be the maximum thickness for which the procedure qualification is valid.

Note 6 — Notch bar impact and hardness tests and macro examination are applicable to class I vessels only (*see* Table 1.1).

Note 7 — For low temperature application, the minimum base metal thickness qualifies '*T*' for thickness below 16 mm and 16 mm for thickness 16 mm and above.

7.3.6 Post Weld Heat Treatment

7.3.6.1 Post weld heat treatment (PWHT) is a variable and requires qualification under each of the conditions mentioned below. The test coupon shall be subjected to heat treatment essentially equivalent to that encountered in the base metal and fabrication of weldments, including at least 80 percent of the aggregate times at that temperature. This 80 percent time limitation is not applicable to post weld heat treatment when it is conducted below the lower transformation temperature:

a) No PWHT;

b) PWHT below lower transformation temperature (for example, tempering);

c) PWHT above upper transformation temperature (for example, normalizing);

d) PWHT shows upper transformation temperature followed by heat treatment below the lower transformation temperature (for example, normalizing or quenching followed by tempering); and

e) PWHT between the upper and lower transformation temperatures.

7.3.6.2 In case the weld is for low temperature application a change from post weld heat treatment and time range in accordance with **7.3.6.1** requires requalification.

7.3.6.3 For the test coupons receiving a post weld heat treatment in which either of the critical temperatures is exceeded the maximum qualified thickness for production welds is 1·1 times the thickness of test coupon.

7.3.7 *Shielding Gas* – In case of gas shielded process a change from a single shielding gas to another shielding gas or to a mixture of shielding gases or a change in the composition of the shielding gas mixture or omission of shielding gas will require requalification. In case of non-ferrous metals, a change of more than 15 percent in the gas flow rate requires requalification.

7.3.8 *Electrical Characteristics* — In case of gas shielded arc process for non-ferrous materials, a change from dc to ac or *vice versa* and in dc welding , change in electrode polarity requires requalification. A change from spray arc, globular arc or pulsating arc to short circuiting arc or *vice versa* requires requalification.

7.4 Non-essential Variables — Variables other than above arc non-essential variables including change of location and does not require fresh procedure qualification for metal arc welding, submerged arc welding and gas shielded arc welding. The WPS may alone be revised to show the non-essential variable where necessary. For other welding processes the essential variables will be drawn in consultation with the Inspection Authority.

7.5 Tests

7.5.1 The following tests are required for procedure qualification (*see* Table 7.1).

7.5.1.1 *Reduced section tensile test* — One test is done to determine the ultimate tensile strength of the groove welded joint.

7.5.1.2 *All weld metal tensile test* — One test is done to determine the ultimate tensile strength and elongation of weld metal.

7.5.1.3 *Guide bend tests* — Guide bend tests as described below are done to determine soundness and ductility of groove weld joints:

a) One transverse root bend up to 10 mm thickness (*see* **7.5.4**);

b) One transverse face bend up to 10 mm thickness (*see* **7.5.4**);

c) Two transverse side bends above 10 mm thickness (*see* **7.5.4**);

d) One longitudinal root bend instead of transverse root bend (*see* **7.5.5**); and

e) One longitudinal face bend instead of transverse face bend (*see* **7.5.5**).

7.5.1.4 *Notched bar impact test* — One set of three charpy V-notch impact test are done in accordance with **7.5.5** to determine notch toughness property of the groove welds (*see also* **7.5.6**).

7.5.1.5 *Macro test* — One test is done in accordance with **7.5.6** to check the complete fusion of the groove weld.

7.5.1.6 *Hardness test*—This is done in accordance with **7.5.7** to check the hardness of weld and heat affected zone (HAZ).

7.5.2 *Reduced Section Tensile Test*—One reduced section tensile test on a test specimen cut transverse to the weld is to be done [*see* IS : 1608-1972 Method of tensile testing of steel products (*first revision*)] as follows.

7.5.2.1 A single specimen of full thickness shall be used for thickness up to and including 25 mm for plates (*see* Fig. 7.2A) and pipes (*see* Fig. 7.2B);

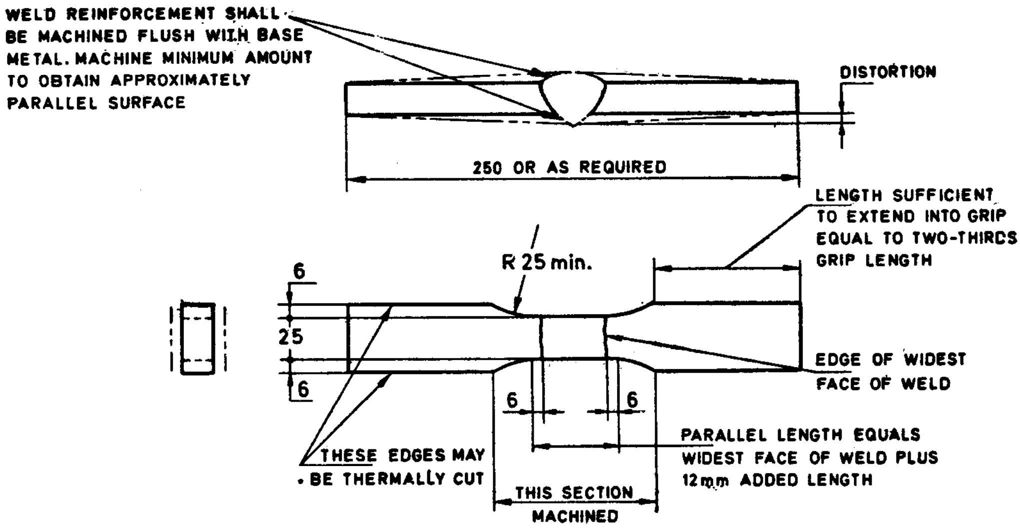
7.5.2.2 For thicknesses above 25 mm single or multiple specimen may be used as necessary for plates and pipes.

7.5.2.3 When multiple specimens are used the specimen shall be cut so as to represent the full thickness of the weld at the location. All the specimens shall represent the full thickness of the weld at one location and each specimen shall be tested.

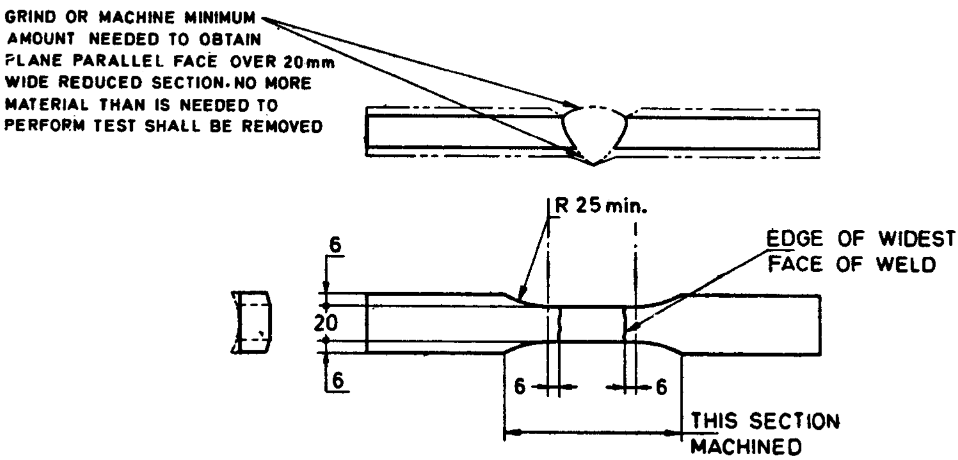
7.5.2.4 For small pipes (such as less than 73 mm O.D.) reduced section specimen as per Fig. 7.2C may be used.

7.5.2.5 Alternatively full section specimen as per Fig. 7.3 may be used.

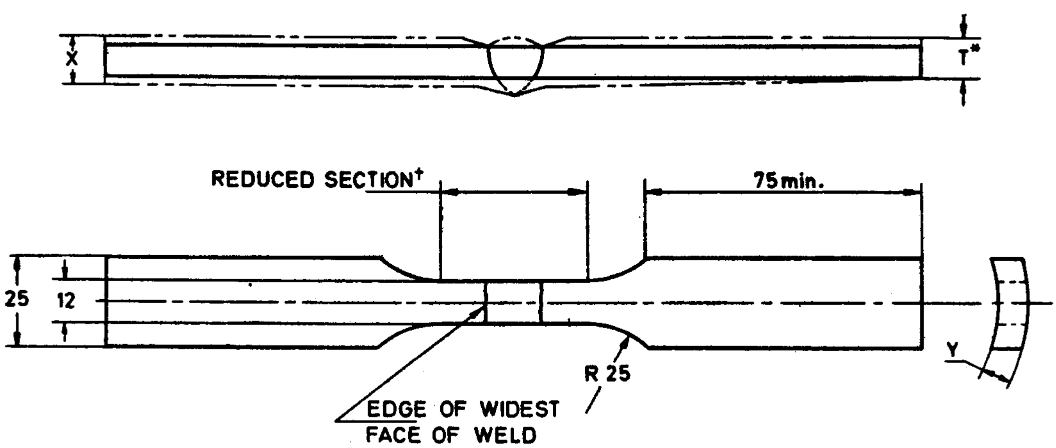
7.5.3 *All Weld Metal Tensile Test* — One all weld metal tensile test on a test specimen taken along the weld is to be done (*see* IS : 1608-1972) on a specimen prepared as shown in Fig. 7.4 (*see* **8.5.6**) as follows



7.2A Reduced Section-Plate



7.2B Reduced Section-Pipe



*The weld reinforcement shall be ground or machined so that the weld thickness does not exceed the base metal thickness '*T*'. Machine minimum amount to obtain approximately parallel surfaces.

†The reduced section shall not be less than the width of the weld plus 2*Y*.

7.2C Reduced Section-Pipe < 75 mm OD

All dimensions in millimetres.

FIG. 7.2 REDUCED SECTION TENSILE TEST SPECIMEN

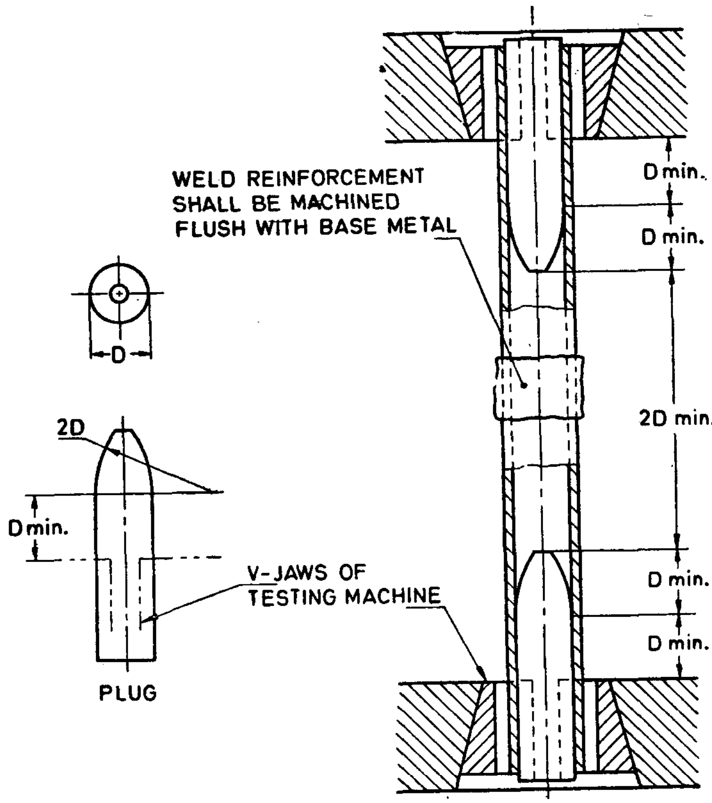
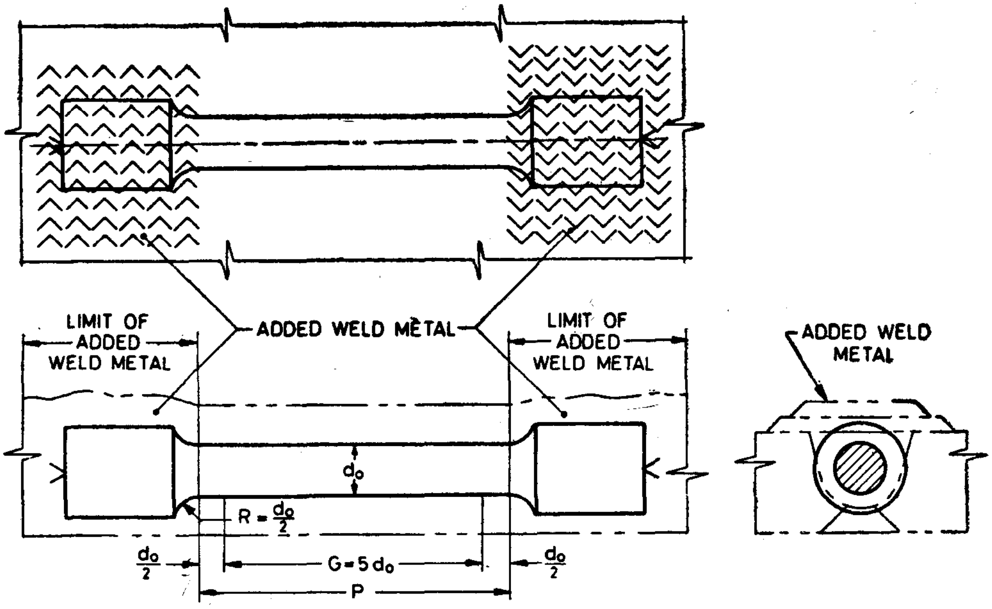


FIG. 7.3 FULL SECTION TENSILE TEST SPECIMEN — SMALL PIPE



NOTE — d_o Maximum possible diameter, need not be more than 16 mm.

FIG. 7.4 ALL WELD METAL TENSILE TEST SPECIMEN

7.5.3.1 The diameter of the test specimen is the maximum possible diameter and this need not be more than 16 mm.

7.5.3.2 The test should include tensile strength, yield strength and elongation.

7.5.3.3 For design temperature above 100 degree celsius the test shall include elevated temperature testing.

7.5.3.4 In case of multiple process or multiple procedure the specimen are to be prepared to represent each process/procedure. The location and size of specimen are selected in consultation with the Inspection Authority.

7.5.3.5 For pipe instead of one all weld metal tensile test, one extra transverse tensile test is to be done (*see* Fig. 7.9).

7.5.4 *Transverse Bend Test* — Two transverse root bend tests and two face bend tests are to be done on test specimens cut transverse to the weld (*see* **8.5.9**). The diameter of former and distance between supports shall be as given in Table 8.2.

7.5.4.1 The specimens are bent such a way that the root surface becomes convex surface in one set and the face surface becomes convex surface in another set (*see* Fig. 7.5A and Fig. 7.5B).

7.5.4.2 When the thickness of plate exceeds 10 mm, face bend and root bend tests are to be substituted by two side bend tests (*see* Fig. 7.5C).

7.5.5 *Longitudinal Bend Test* —Transverse bend tests may be substituted with one face bend and one root longitudinal bend test (*see* Fig. 7.6), when the weld metal and the parent metal differ markedly in bending properties either between dissimilar parent metals or weld metal and parent metal. The tests shall be done as per transverse bend test procedure (*see* **7.5.4**).

7.5.6 *Notched Bar Impact Test* — One test of three V-notch impact test specimens transverse to the weld is to be tested as per **8.5.8** of the code. In case of welds for low temperature application, three more impact test specimens shall be taken from the heat affected zone and tested.

7.5.7 *Macro Test* — One macro test on a specimen cut transverse to the weld is to be done to determine the complete fusion and free from cracks, as per the code (*see* **8.5.11**).

7.5.8 *Hardness Test* — Hardness test is to be done on the macro test specimen along the cross section of the weld and the heat affected zone. The hardness shall be assessed by a HV indentor of not more than 30 kgf load.

7.5.9 *Preparation of Test Coupon* — The base metal and filler metal shall be as per **7.7**.

7.5.10 *Order of Removal of Test Specimens* — The test specimens are removed from the test coupon as detailed below:

a) Where transverse bend tests are required, the test specimens are removed as shown in Fig. 7.7.

b) Where longitudinal bend tests are required, the test specimens are removed as shown in Fig. 7.8.

c) Where test is done on a pipe, the test specimens are removed as shown in Fig. 7.9.

7.6 Acceptance Criteria — In order to pass the test, specimens shall have the following minimum requirements.

7.6.1 *Transverse Tensile Test*

7.6.1.1 Specified minimum tensile and yield strength of base metal.

7.6.1.2 In case of two different metals, specified minimum strength of the weaker of the two.

7.6.1.3 If the specimen breaks outside the fusion line, the test shall be accepted as meeting the requirement provided the strength is more than 95 percent of the minimum tensile strength of the base metal.

7.6.2 *All Weld Metal Test*

7.6.2.1 The tensile strength and/or yield strength shall not be less than the corresponding specified minimum values for the parent metal.

7.6.2.2 The elongation shall not be less than 80 percent of the minimum elongation specified for the base metal corrected for the gauge length if different from 5 d_0.

7.6.2.3 For elevated temperature test, the values shall not be less than corresponding values for the base metal at the appropriate temperature.

7.6.3 *Bend Tests*

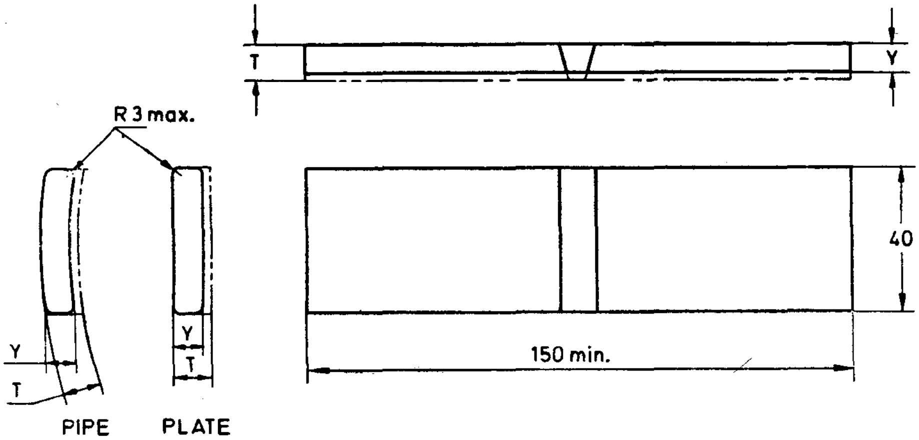
7.6.3.1 The weld and heat affected zone of a transverse bend specimen shall be completely within the bent portion of the specimen after testing.

7.6.3.2 The specimen shall have no open defect in the weld or heat affected zone exceeding 3 mm measured in any direction on the convex surface of the specimen.

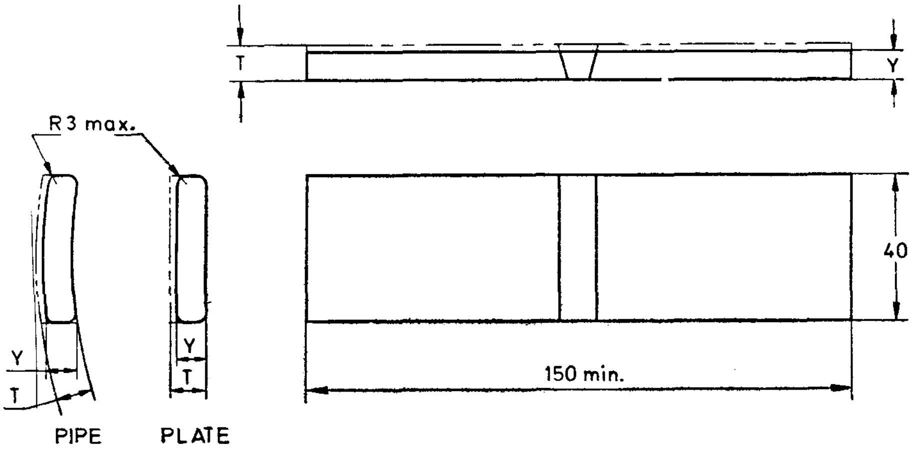
7.6.3.3 Cracks occurring on the corners of the specimen during the testing shall not be considered unless there is definite evidence that they result from slag inclusions or other internal defects.

7.6.4 *Impact Test* — The minimum average results from the impact test shall be 2·6 kgf/cm² and the minimum value for any test specimen shall be 2·0 kgf/cm².

7.6.5 *Macro Examination* — Visual examination of the cross section of the weld metal and heat affected zone (HAZ) shall show complete fusion and shall be free from cracks.



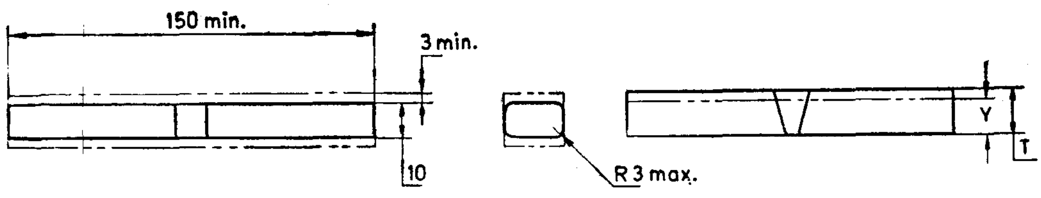
7.5A Face-Bend Specimen — Plate and Pipe



Special Notes for 7.5A and 7.5B

1. *Y* = *T* when *T* is 1·5 mm to 10 mm.

7.5B Root Bend Specimen — Plate and Pipe



Special Notes for 7.5C

1. When specimen thickness *T* exceeds 20 mm, use one of the following:
   1.1 Cut specimen into multiple test coupons *Y* of approximately equal dimensions (10 mm tc 40 mm).
   Y = tested specimen thickness when multiple specimens are taken from one coupon.
   1.2 The specimen may be bent at full width.
2. *Y* = *T* when *T* is 10 to 20 mm.

7.5C Side Bend Specimen — Plate and Pipe

NOTE 1 — Weld reinforcement and backing strip or backing ring, if any shall be removed flush with the surface of the specimen.

NOTE 2 — If the pipe being tested is 100 mm nominal diameter or less, the width of the bend specimen may be as follows:

2.1 20 mm for diameters 50 mm to 100 mm including
2.2 10 mm for diameters less than 50 mm to 10 mm including
2.3 Alternatively, if the pipe is 25 mm nominal dia or less, the width may be that obtained by cutting the pipe into quarter sections, less an allowance for cutting. These specimens are not required to have one surface machined flat as shown.

NOTE 3 — If the surfaces of bend specimen are gas cut, removal by machining or grinding of not less than 3 mm from the surface shall be required.

All dimensions in millimetres.

FIG. 7.5 TRANSVERSE BEND TEST SPECIMENS

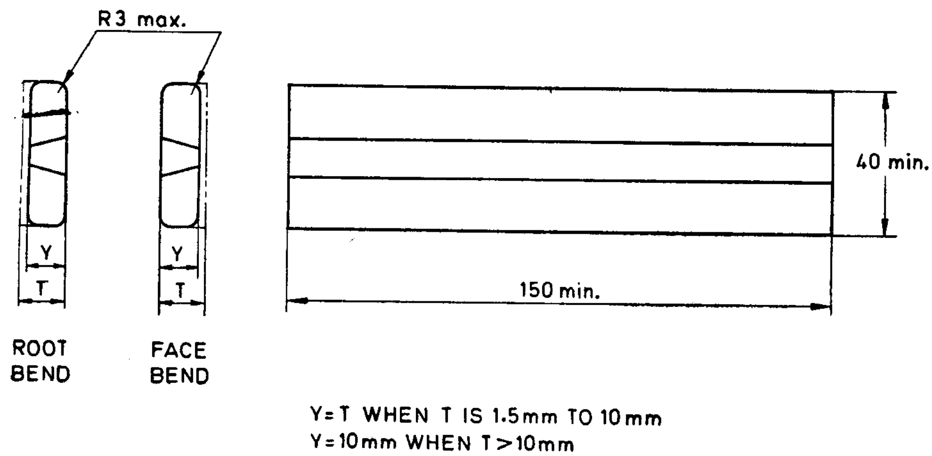


FIG. 7.6 LONGITUDINAL BEND TEST SPECIMEN

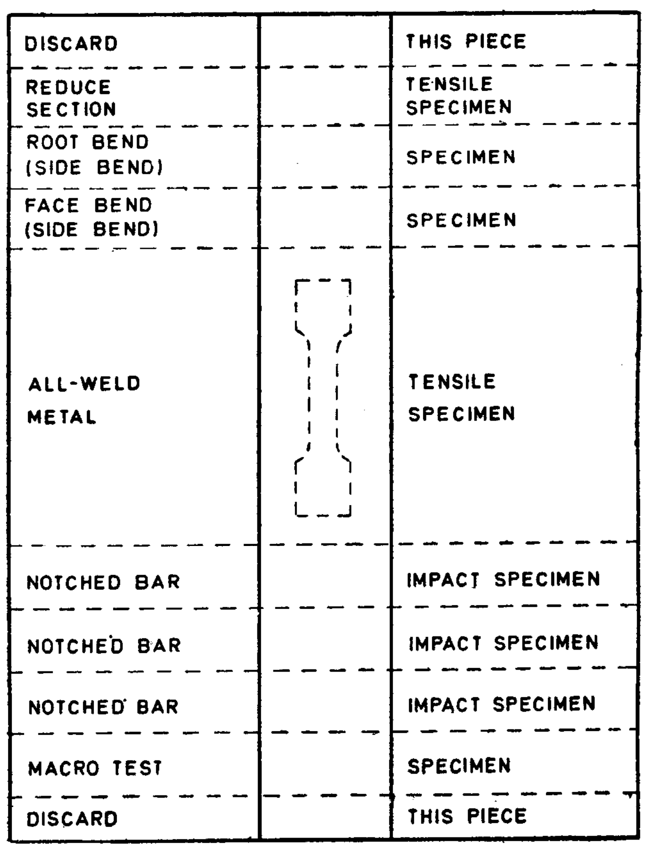


FIG. 7.7 ORDER OF REMOVAL OF TEST SPECIMENS FROM PLATE-TRANSVERSE BEND PROCEDURE QUALIFICATION

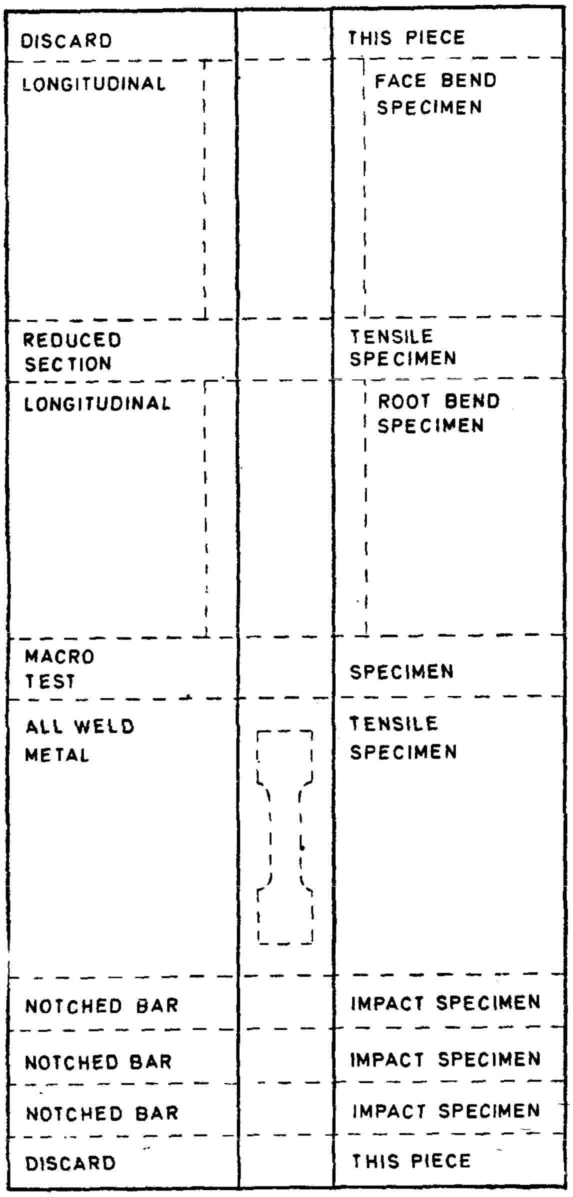


Fig. 7.8 Order of Removal of Test Specimens, Plate-Longitudinal Bend Procedures Qualification

7.6.6 *Hardness Test* — The maximum Vicker's hardness value of the weld metal and heat affected zone (HAZ) shall not exceed the following values (*see also* Table 6.3).

7.6.6.1 225 HV for steels of metal group 0, 1a and 1b.

7.6.6.2 240 HV for steels of metal group 2.

7.6.6.3 250 HV for steels of metal group 3 and 4.

7.6.7 *Acceptance of Procedure Qualification Record (PQR)* — The results of the test and the examination of the test coupons shall satisfy the above requirements for acceptance.

7.6.8 *Records* —Records of all tests (*see* **7.1.3**) shall be kept by the manufacturer for a period of at least 5 years after the inspection of the pressure vessel and shall be available for the Inspecting Authority for examination when required. Proforma for keeping records is given in Appendix H.

7.6.9 *Qualification of Welding Procedure Specification (WPS)*

7.6.9.1 Qualification of plate qualifies for the pipe and *vice versa.*

7.6.9.2 Qualification on a groove weld qualifies the fillet weld of all sizes on all base metal thicknesses as permitted in Table 7.1.

7.6.9.3 Qualification on a groove weld qualifies partial penetration groove welds for the thickness of deposited weld metal qualified as indicated in Table 7.1.

7.6.9.4 The range of base metal thickness and weld metal thickness qualified as is indicated in Table 7.1.

7.6.9.5 WPS qualified on groove welds shall be applicable for production welds between dissimilar base metal thicknesses provided:

a) The thickness of thinner member shall be within range permitted.
b) The production joints shall be within the thickness range permitted in Table 7.1.
c) Alternatively, the maximum thickness permitted in Table 7.1 may be adopted for thicker member provided the qualification was made on the base metal of thickness 40 mm or more.
d) More than one PQR may be required to qualify for some dissimilar thickness combination.

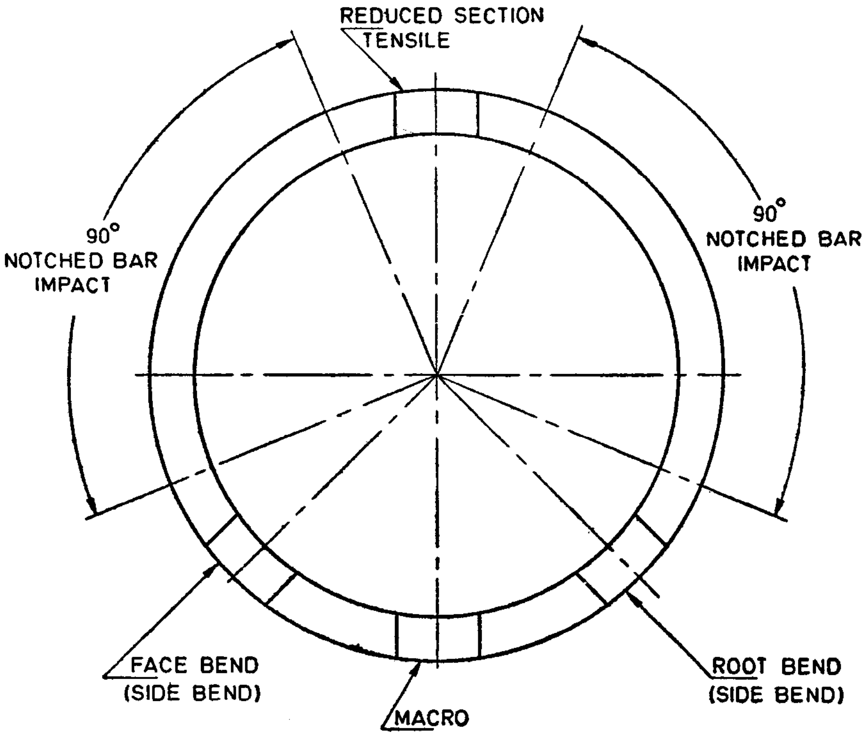
7.7 Preparation of Test Coupon — The base metal and filler metal shall be one or more of those listed in the WPS. The dimension of the test coupon shall be sufficient to provide the required test specimens. The base metal may consist of either a plate or a pipe. Qualifications of plate also qualifies the pipe and *vice versa.*

7.7.1 The order of removal of test specimens for plates and pipes are shown in Fig. 7.7 to 7.9.

7.7.2 The test coupon shall qualify the thickness ranges of both base metal and the deposited weld metal to be used in production. Limits of qualification shall be in accordance with Table 7.1.

7.7.3 The WPS made as above on groove weld qualifies the fillet weld for all fillet sizes on all base metal thicknesses.

7.7.4 The WPS made as above on groove weld qualifies partial penetration groove welds for the deposited metal thickness indicated in Table 7.1.



NOTE — Weld extra test piece to accommodate one extra transverse tensile specimen in place of all weld metal tensile and to accommodate three impact specimens, if required.

FIG. 7.9 ORDER OF REMOVAL OF TEST SPECIMENS, PIPE-PROCEDURE QUALIFICATION

7.8 Welder's Performance Qualification

7.8.1 Each manufacturer or contractor shall be responsible for conducting tests to qualify the performance of the welders or welding operators in accordance with one of this welding procedure specification (WPS). The welders or welding operators shall be tested under the supervision and control of the manufacturer or contractor. The welding performed by the welder or welding operator in another organization is not to be considered.

7.8.2 *Qualification Tests* — The performance qualification tests are intended to determine the ability of the welder or welding operator to make sound welds. The manufacturer or contractor shall qualify each welder or welding operator for each welding process to be used in production welding. The performance tests can be either for groove weld or for fillet weld.

7.8.2.1 The welder or welding operator who welds the PQR test coupons is also qualified within the limits of the performance qualification listed in this section (*see* **7.8.5**).

7.8.2.2 A welder or welding operator qualified to weld in accordance with one qualified WPS is also qualified to weld in accordance with other qualified WPS using the same welding process within the limits of variables listed in this section (*see* **7.8.7**).

7.8.2.3 Each qualified welder or welding operator shall be assigned an identification which shall be used to identify the work of that welder or welding operator.

7.8.2.4 The record of welder or welding operator performance tests shall be kept by the manufacturer. This shall include the welding variable, the type of test, tests results and ranges qualified for each welder and welding operator. Pro-forma for keeping records is given in Appendix H.

7.8.3 *Groove Welds*

7.8.3.1 *Mechanical test* — The type and number of test specimens required shall be in accordance with Table 7.2. The order of removal of test specimen is shown in Fig. 7.10. The acceptance shall be in accordance with **7.6.**

7.8.3.1.1 Mechanical testing as given in Table 7.2 may be substituted by radiography on a test bed of 225 mm length. Acceptance standard for radiography shall be as per Class I vessels. Qualification by radiography is not permitted for gas metal arc welding.

7.8.3.2 *Test coupon for pipes* — The test coupons for pipes shall be removed as shown in Fig. 7.11 for mechanical testing. The acceptance shall be in accordance with **7.6.**

TABLE 7.2 GROOVED-WELD PERFORMANCE QUALIFICATIONS THICKNESS LIMITS AND TEST SPECIMENS

(*Clause* 7.8.3.1)

Thickness T of the Test Coupon Welded (*see* Note 1) mm	Thickness t of Deposited Weld Metal Qualified (*see* 7.8.6 and Note 2) mm	Type and Number of Test Required			
		Side Bend	Face Bend (*see* Notes 3 and 4)	Root Bend	Macro
Up to 10	$2t$	(*see* Note 5)	1	1	1
10 but less than 20	$2t$	2	—	—	1
20 and above	Maximum to be welded	2	—	—	1

Note 1 — The entire thickness of groove joint test coupon shall be filled with deposited weld metal.

Note 2 — Two or more pipe test coupons of different thicknesses may be used to determine the deposited weld metal thickness qualified and that thickness may be applied to production welds to the smallest diameter for which the welder is qualified.

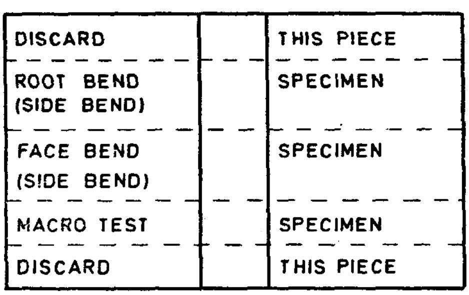
Note 3 — A total of four specimens is required to qualify for multiple positions as prescribed in Fig. 7.11B.

Note 4 — Face and root-bend tests may be used to qualify combination test of:

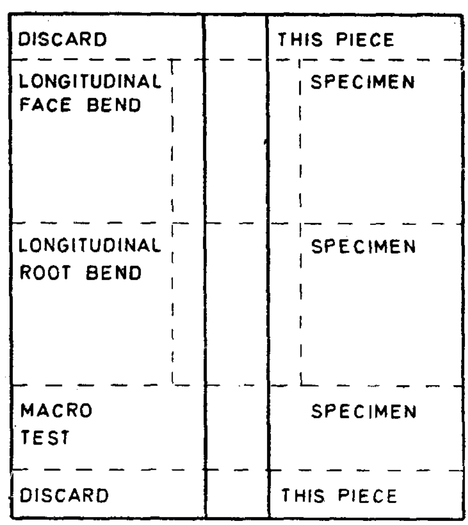
4.1 One welder using two welding processes; or

4.2 Two welders using the same or a different welding process.

Note 5 — Two side bend tests may be substituted for the required face and root-bend tests.



7.10A Transverse Bend



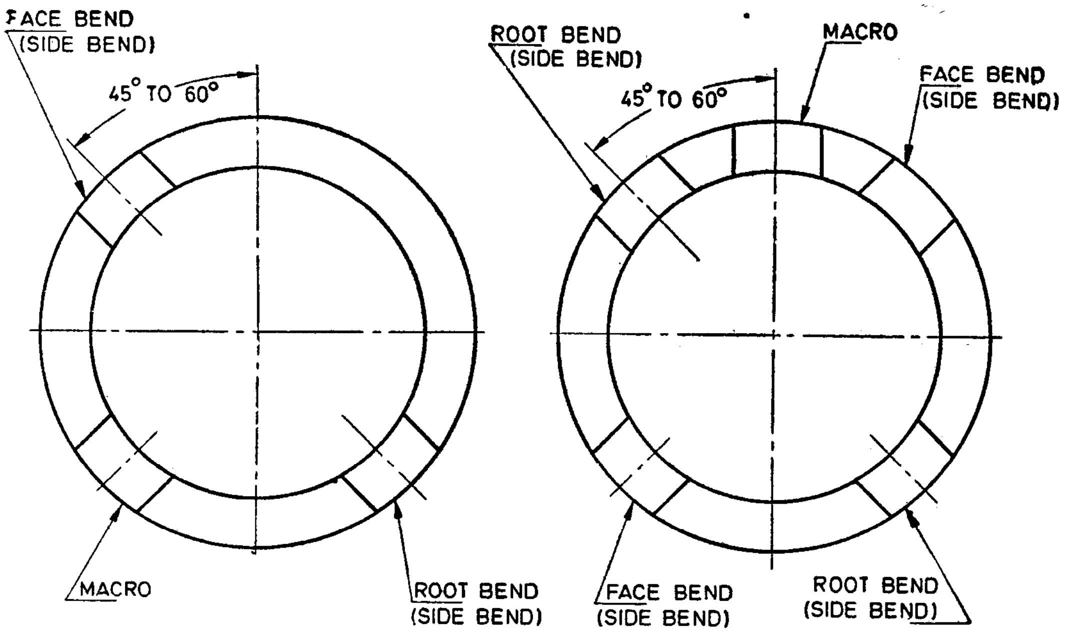
7.10B Longitudinal Bend

Fig. 7.10 Order of Removal of Test Specimen, Plate — Performance Qualification

7.8.4 *Fillet Welds*

7.8.4.1 *Mechanical test* — For fillet welds, fracture test and macro examination shall be done. The dimension and preparation of test specimen shall be in accordance with Fig. 7.12 for plate and Fig. 7.13 for pipe. The test specimen shall not contain any visible cracks.

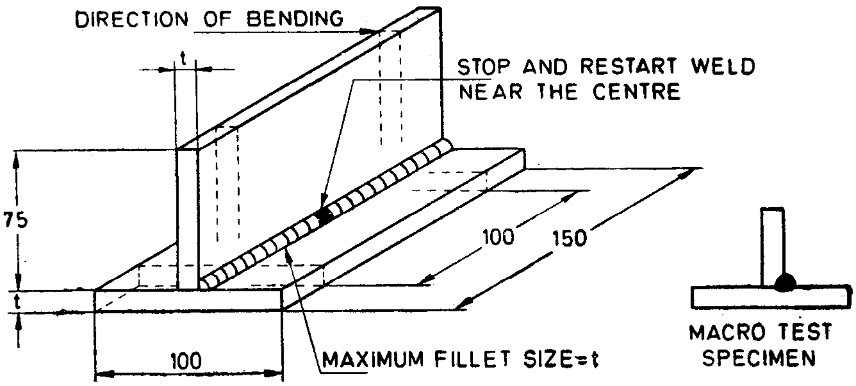
7.8.4.2 The specimen for fracture test is taken as shown in Fig. 7.12 and Fig. 7.13 and shall be loaded laterally in such a way that the root of the weld is in tension. The load shall be steadily increased until the specimen fractures or bends flat upon itself. The fractured surface shall show no evidence of cracks or incomplete root fusion and the sum of the length of inclusion and porosity visible on the fractured surface shall not exceed 10 mm for plate and 10 percent of the quarter section for pipe.



7.11A Flat or Horizontal

7.11B Multiple Horizontal and Multiple-Inclined

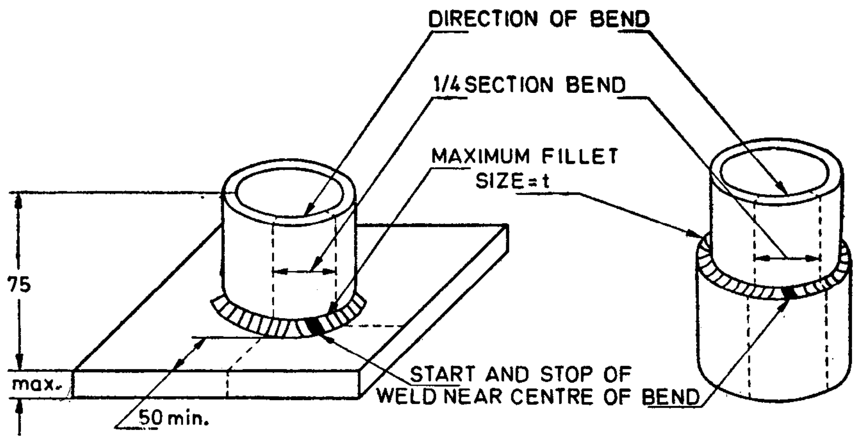
FIG. 7.11 ORDER OF REMOVAL OF TEST SPECIMENS, PIPE-PERFORMANCE QUALIFICATION



t = 5mm TO 10mm

All dimensions in millimetres.

FIG. 7.12 FILLET WELD IN PLATE-PERFORMANCE QUALIFICATION



t = WALL THICKNESS

NOTE — Either pipe to plate or pipe to pipe may be used as shown.

All dimensions in millimetres.

FIG. 7.13 FILLET WELD IN PIPE-PERFORMANCE QUALIFICATION

7.8.4.3 The cut end of one of the end section shall be smoothed and etched with a suitable etchant (*see* Appendix K) to give a clear definition of the weld metal and heat affected zone. The visual examination shall show complete fusion and free from cracks except that the linear indications at the root shall not exceed 0·8 mm. The weld shall not have a concavity or convexity greater than 1·5 mm and the difference in length of legs of fillet shall not exceed 3 mm.

7.8.4.4 For fillet welds the basic position for plates and pipes are described in Fig. 7.14 and 7.15.

7.8.4.5 The limitations and number of tests required for fillet weld performance shall be as shown in Table 7.3 for plate, Table 7.4 for fillet qualification by groove weld and Table 7.5 for small diameter pipe fillet weld.

7.8.5 *Limits of Qualified Positions*

7.8.5.1 Welders who pass the required tests in groove welds in test positions (*see* Fig. 7.1) shown in Table 7.6 shall be qualified for the position of groove welds, including branch welds, shown in Table 7.6 and the fillet welds (*see* Fig. 7.14 and Fig. 7.15) shown in Table 7.6. In addition, the welders who pass the required test for groove welds shall also be qualified to make fillet welds and in all thicknesses and pipe diameters of any size within the limits of the welding variables (*see* **7.8.7**).

7.8.5.2 Welders who pass required test for fillet welds in the test position of Table 7.6 shall be qualified for the positions shown in this table. Welders who pass the test for fillet weld on plate shall be qualified to make fillet weld only in all thicknesses of material, sizes of fillet weld and pipes and tubes 73 mm outside diameter and over, within the essential variable. Welders who make fillet weld in pipe or tube less than 73 mm outside diameter shall pass the pipe fillet test in accordance with **7.8.4.5**.

7.8.5.3 A fabricator who does production welding in a special orientation may make the test for performance qualification in this specific orientation. Such qualification is valid only for the position actually tested except that an angular deviation of $\pm$ 15° is permitted in the inclination of the weld.

7.8.6 *Qualification Test Coupons*

7.8.6.1 The test coupons may be plate or pipe. When all position qualifications for pipe are accomplished by welding one pipe assembly in both horizontal and multiple positions, large diameter pipes shall be employed to make up the test coupons as illustrated in Fig. 7.16.

7.8.6.2 The dimensions of the welding groove of the test coupons used in making double welded groove welds or single welded groove welds with backing shall be the same as those of any welding procedure or shall be as shown in Fig. 7.17. Partial penetration groove welders or fillet welds are considered as welding with backing.

7.8.6.3 The dimensions of the welding groove of the test coupon used in making qualification tests for single welded groove welds without backing shall be the same as those for any WPS qualified by the manufacturer or as shown in Fig. 7.18.

7.8.7 *Welding Variables*

7.8.7.1 A welder or welding operator shall be qualified whenever a change is made in one or more of the essential variables listed. When a combination of welding process is required to make a weldment, each welder shall be qualified for the particular welding process or processes he will be required to use in production welding. A welder may be qualified by making tests with each individual welding process or with the combination welding process in a single test coupon. The limits of thickness for which the welder is qualified is dependent upon the thickness of test coupon as given in Table 7.6. The following are the essential variables and require requalification of welder or welding operator.

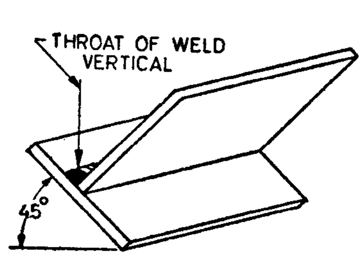
7.8.7.2 *Joints* — The deletion of backing and change in root detail in single welded groove welding. Double welded groove welds are considered as welding with backing.

7.8.7.3 *Base metal* — The change in the pipe diameter beyond the range qualified specified in Table 7.7 and thickness beyond the range specified in Table 7.2.

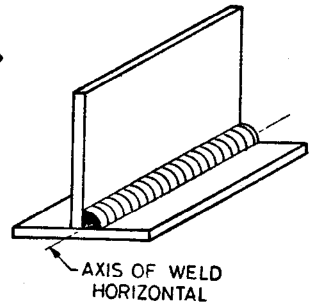
7.8.7.4 *Filler metal* — A change in classification of filler metal and a change in deposited weld metal thickness beyond the limit specified in Table 7.2. A change in more than one-third in the diameter of electrode for root run of manual metal arc welding.

7.8.7.5 *Positions* — The addition of other welding positions than those already qualified specified in Table 7.6 (*see* **7.2**, **7.8.4** and **7.8.7.7**). For process other than submerged arc welding, a change from upwards to downwards or *vice versa* in the progression specified for any pass of a weld except that cover or wash pass may be up or down. The root pass may also be run either up or down when the root pass is removed to sound weld metal in the preparation for welding the second side.

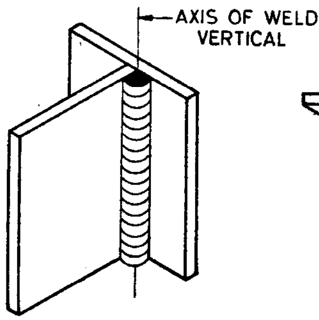
7.8.7.6 *Shielding gas* — The emission of inert gas shielding (backing) except that requalification is not required when a qualified WPS is changed to emit the inert gas backing. This procedure is used for a single welded butt joint with a backing strip or a double welded butt joint or a fillet weld and in case of non-ferrous metals a change of more than 15 percent in the gas flow rate.



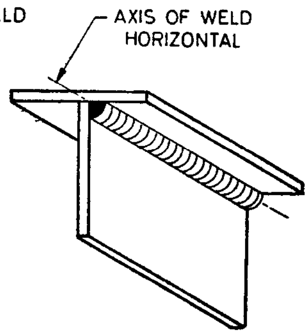
7.14A Flat Position of Test Tee for Fillet Weld



7.14B Horizontal Position of Test Tee for Fillet Weld



7.14C Vertical Position of Test Tee for Fillet Weld



7.14D Overhead Position of Test Tee for Fillet Weld

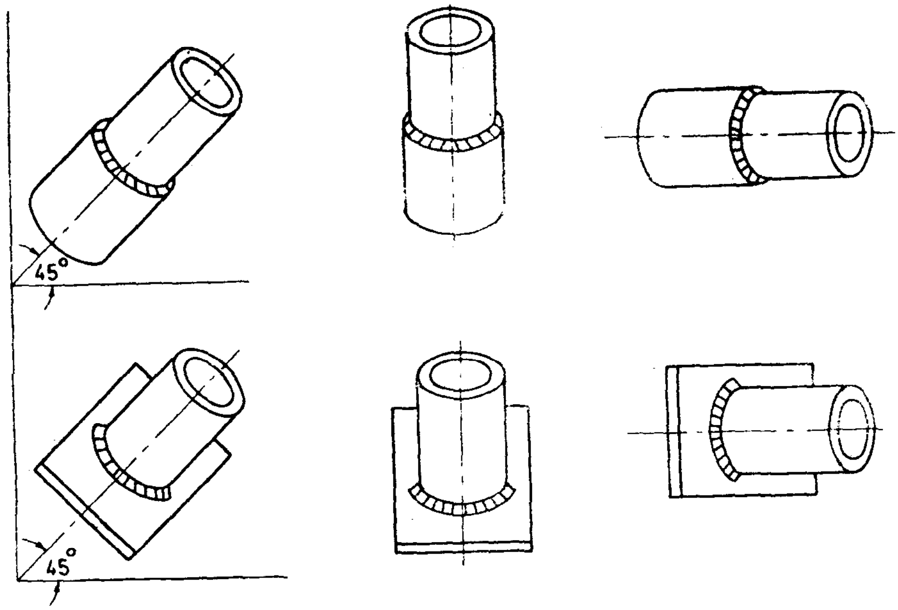
Fig. 7.14 Positions of Test Plates for Welder Performance Qualification of Fillet Welds

TABLE 7.3 PLATE FILLET-WELD TEST

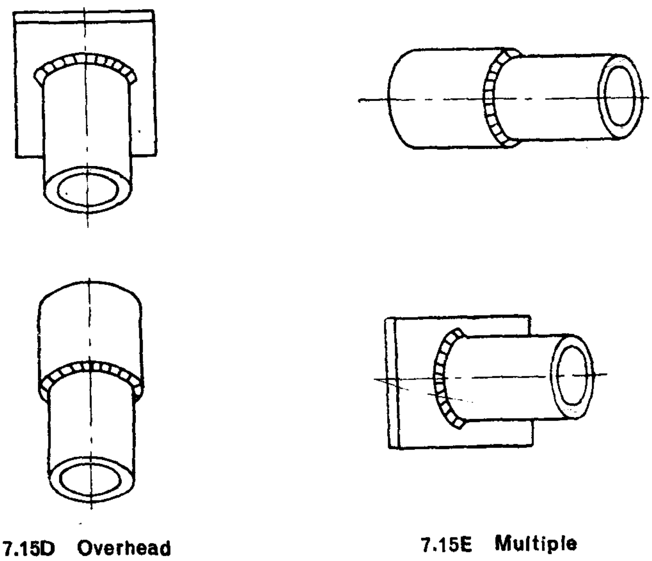
Type of Joint	Thickness *t* of Test Coupon as Welded mm	Range Qualified	Number of Specimens Required (*see* Fig. 7.12)	
			Macro	Fracture
Tee fillet	5 to 10	All base material thicknesses, fillet sizes, and diameters 73 mm O. D. and over	1	1

TABLE 7.4 FILLET QUALIFICATION BY PLATE OR PIPE GROOVE-WELD TESTS

Type of Joint	Thickness *t* of Test Coupon as Welded	Range Qualified	Type and Number of Tests Required
Any groove	All thicknesses	All base material thicknesses, fillet sizes, and diameters	Fillet welds are qualified when groove weld is qualified in accordance with either Table 7.1 or Table 7.7



7.15A Flat (Rotated)　　7.15B Horizontal　　7.15C Vertical (Rotated)



7.15D Overhead　　7.15E Multiple

Fig. 7.15 Positions of Test Pipes for Welder Performance Qualification of Fillet Welds

TABLE 7.5 SMALL DIAMETER PIPE FILLET-WELD TEST

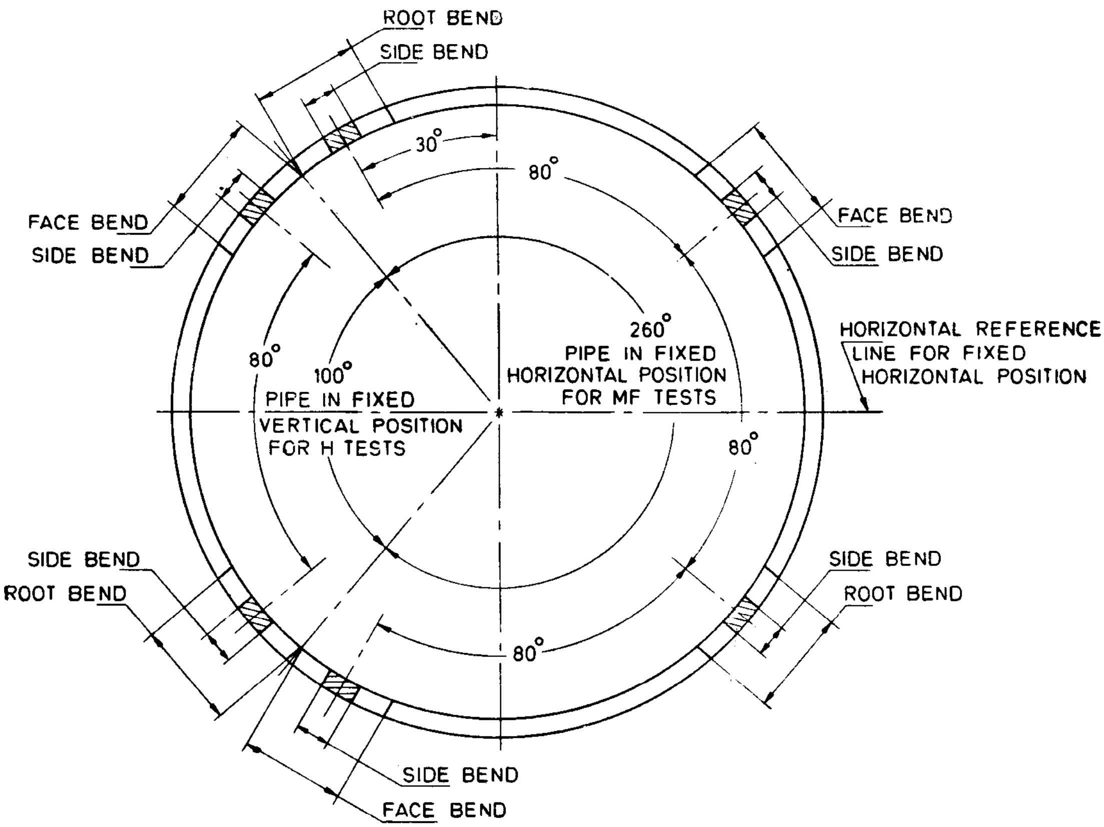
Nominal Pipe Size of Sample Weld	Outside Diameter Qualified (No Maximum)	Pipe Wall Thickness Qualified	Number of Specimens Required (*see* Fig. 7.12)	
			Macro	Fracture
Less than 20 mm	Minimum of not less than size welded	All	1	1
20 to 50 mm	Over 25 mm	All	1	1
Over 50 mm	73 mm and over	All	1	1

TABLE 7.6 PERFORMANCE QUALIFICATION POSITION LIMITATIONS

Qualification Test		Position and Type Weld Qualified (Note 1)		
Weld	Position	Groove Plate and Pipe Over 600 mm OD	Pipe	Fillet Plate and Pipe
Plate-Groove	*F*	*F*	*F* (Note 2)	*F*
	H	*F, H*	*F, H* (Note 2)	*F, H*
	V	*F, V*	*F* (Note 2)	*F, H, V*
	O	*F, O*	*F* (Note 2)	*F, H, O*
	V and *O*	*F, V, O*	*F* (Note 2)	All
	H, V and *O*	All	*F, H* (Note 2)	All
Plate-Fillet	*F*	—	—	*F* (Note 2)
	H	—	—	*F, H* (Note 2)
	V	—	—	*F, H, V* (Note 2)
	O	—	—	*F, H, O* (Note 2)
	V and *O*	—	—	All (Note 2)
Pipe-Groove	*F*	*F*	*F*	*F*
	H	*F, H*	*F, H*	*F, H*
	MF	*F, V, O*	*F, V, O*	All
	MI	All	All	All
	H and *MF*	All	All	All
Pipe-Fillet	*F*	—	—	*F*
	H	—	—	*F, H*
	V	—	—	*F, H*
	O	—	—	*F, H, O*
	V and *O*	—	—	All

Note 1 — Position of welding shown in Fig. 7.1 and Fig. 7.14.
Note 2 — Pipes 73 mm OD and over.

F = Flat
H = Horizontal
V = Vertical
O = Overhead
MF = Multiple Fixed
MI = Multiple Inclined



Note 1 — Side bend may be substituted for face and root bends for thickness above 10 mm.
Note 2 — Acceptance as per **7.6.**

Fig. 7.16 Order of Removal of Test Specimens from Pipe — All Position-Performance Test

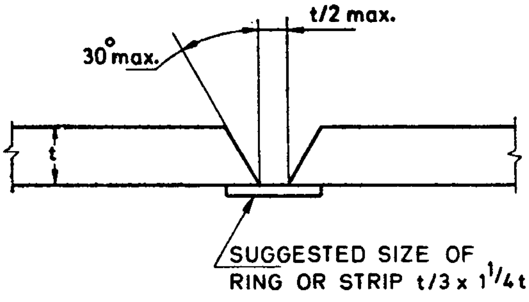


FIG. 7.17 SINGLE WELDED GROOVE-JOINT WITH BACKING

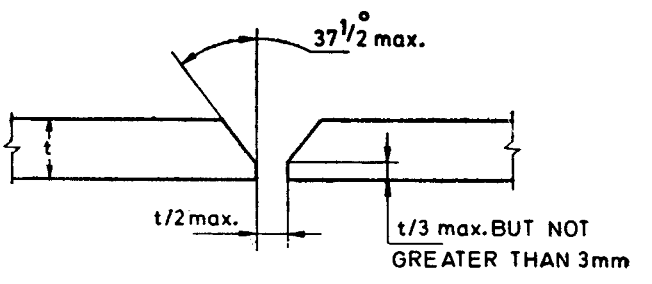


FIG. 7.18 SINGLE WELDED GROOVE-JOINT WITHOUT BACKING

TABLE 7.7 PIPE GROOVE — WELDS DIAMETER LIMITS — PERFORMANCE QUALIFICATION

NOMINAL PIPE SIZE OF SAMPLE WELD	OUTSIDE DIAMETER QUALIFIED (NO MAXIMUM) mm
Less than 20 mm	Minimum of not less than size welded
20 to 50 mm	Over 25 mm
Over 50 mm	73 mm and over

7.8.7.7 *Electrical characteristics* — In case of gas shielded welding a change from ac to dc or *vice versa* and in dc welding a change in the electrical polarity. For gas shielded arc welding a change from spray arc, globular arc or pulsating arc to short circuiting arc or *vice versa.*

7.8.7.8 *Non-essential Variables* — Variables other than above are non-essential variables including changes of location and does not require fresh performance qualification for metal arc welding, submerged arc welding and inert gas arc welding. For other welding processes this is to be drawn in consultation with the Inspection Authority.

7.8.8 *Re-tests* — A welder or welding operator who fails to meet the requirement of one or more of the test specimens prescribed in Table 7.2 may be retested under following conditions.

7.8.8.1 When the qualification coupon has failed in mechanical testing in accordance with **7.8.4.1**, retesting shall be by mechanical testing. When an immediate retest is made, the welder or welding operator shall make two consecutive test coupons for each position for which he has failed, all of which shall pass the test requirement.

7.8.9 *Renewal of Qualification* — The performance of the welder or welding operator shall be affected under the following conditions.

7.8.9.1 When he has not welded with a process during a period of 3 months or more, his qualification for that process shall be expired, except when he is welding with another process, the period may be extended to 6 months.

7.8.9.2 When he has not welded with any process dnring a period of 3 months all his qualification shall be expired including any of which may have extended beyond 3 months by virtue of **7.8.9.1**.

7.8.9.3 When there is a specific reason to question his ability to make welds that meet the specification which support the welding that he is doing his qualification be considered expired.

7.8.9.4 Renewal of qualification for a specific welding process under **7.8.9.1** or **7.8.9.2** may be made in a single test joint, plate or pipe on any thickness, position or material to re-establish welder or welding operator qualification for any thickness, position or material for the process for which he was previously qualified.'

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Printed at Kay Kay Printers, Delhi-7